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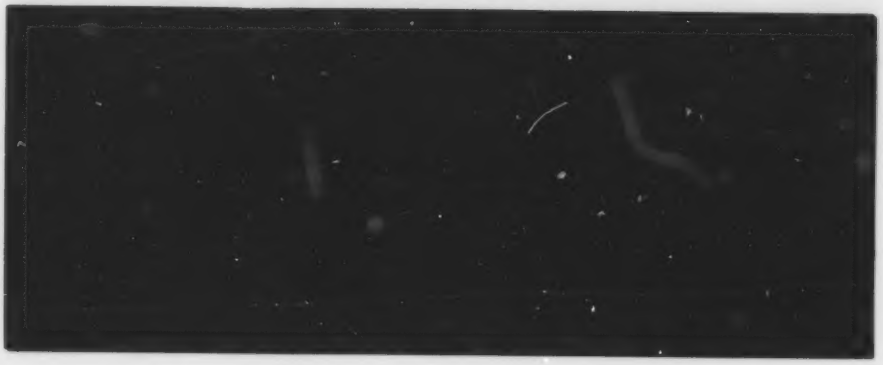

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The lesser clover leaf weevil, *Hypera nigrirostris* (Fabr.) (Coleoptera: Curculionidae); ecology and control in red clover (*Trifolium pratense* [L.]) seed crops in Saskatchewan

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June, 1989

Final Report on Project No. 1.2-10
Agriculture Development Fund

EXECUTIVE SUMMARY

Abstract

Objectives were: 1) to study the life history of the lesser clover leaf weevil (LCLW) on red clover in Saskatchewan; 2) to identify parasitoids of LCLW and measure their effects on LCLW populations; 3) to examine LCLW damage to red clover; and 4) to develop a sampling plan for estimating the density of egg and larval LCLW populations.

LCLW life history is closely coordinated with red clover development. Densities of P2 larvae (most destructive stage) greater than 3 per shoot may damage up to 50% of buds and flowerheads. Parasitoids and environmental factors maintain LCLW populations at low densities in most years. Egg and larval populations should be monitored by collection of 5-shoot bouquet samples in June and early July.

Summary

During 1986 and 1987, a study was made of the life history of, parasitoids of, and damage to red clover caused by the lesser clover leaf weevil (LCLW). Overwintered adults (blue-green) began feeding and mating in April/May and laid eggs soon after in stipules, stems and leaves. Four larval stages occurred; the first two were grouped as P1 larvae (collected from mid May till mid August), the third and fourth as P2 larvae (late May till mid August). Larvae fed in stipules, leaves, stems, buds and flowerheads. Pupation occurred on flowers, leaves, stipules, and ground debris from late June till mid August. Newly emerged adults were brown but became bright green after about a week. Total development time was about 4 weeks in the laboratory (constant 22 C) and about 6-9 weeks under field conditions.

Parasitoids (eight species in total) were reared only from larvae and pupae of LCLW. A braconid wasp parasitised almost 25% (1987 seasonal average, with >40% parasitism in some weekly samples) of P2 larvae (the most destructive weevil stage), while an ichneumon fly parasitised upto 50% of LCLW pupae in some weekly samples (seasonal averages were 35 and 27% in 1986 and 1987, respectively). By reducing feeding activity or causing death of the LCLW larvae, these parasitoids may markedly reduce the damage potential to red clover of the LCLW. Offsetting this benefit is the fact that some of the other parasitoids associated with LCLW may parasitise the braconid and ichneumonid.

Weekly damage assessments showed that feeding (on young leaves or stems) by overwintered adults had little effect on plant growth or flowering. New season adults fed on mature leaves and secondary growth near the plant base; they were also observed to feed on florets, occasionally destroying upto 50% of the florets in a flowerhead, and on petioles causing complete

loss of the flowerhead. These types of feeding might cause decreased seed yield in years of high adult populations. Feeding by P1 larvae caused minor damage. P2 larvae at densities greater than three per 5-shoot bouquet, have the potential to cause more than 50% damage to buds and flowerheads. However, in an analysis of damage potential of LCLW larvae, at least three additional factors must be considered, namely, red clover growth rate, the plant's stage of development, and the extent of parasitism. These factors are significantly influenced by the season's weather conditions, especially temperature and precipitation. The greatest damage potential occurs when peak P2 larval density coincides with the onset of the red clover bud stage, as happened in 1986. In that year, possible drought stress caused the red clover to enter its flowering stage sooner than normal, coincident with the presence of P2 larvae. By contrast, in 1987 when precipitation (April to July inclusive) was about 50% greater than in 1986 (and closer to the long-term value), most P2 feeding occurred prior to the appearance of reproductive structures, and damaged shoots showed no decrease in buds or flowers.

To estimate an insect population's size (and, therefore, for a pest its damage potential), it is essential to develop an 'optimal sampling plan' (defined as the smallest sample size that assures the desired reliability of the estimate). Thus, a critical part of the current project was the development of such a plan for the LCLW. It is recommended that LCLW (eggs, P1 and P2 larvae) populations be monitored by collection of 5-shoot bouquet samples in June and early July to assess damage potential.

Abstract

In 1986 and 1987, investigations were made on the biology of, and the effects of parasitism on, and chemical control of, the lesser clover leaf weevil (LCLW) (Hypera nigrirostris [Fab.]) and on the damage caused by the weevil to red clover (Trifolium pratense [L.]) grown for seed.

Weevil populations were sampled weekly from May to early August. LCLW adults overwinter in red clover fields and begin to feed, mate, and oviposit in late April or early May. Eggs were located on stipules, shoots and leaves from early May until early June. Larvae were located on shoots and collected from June until August. Pupae were collected on shoots and in debris from late June until August.

Larvae and pupae were parasitized by five hymenopterous species; hyperparasites, representing two genera, were also identified. Parasites appear to be an important factor for controlling weevil populations.

P2 (third and fourth instars) larvae were responsible for the majority of damage to stipules, buds, and flowers resulting in potential loss in seed yield; P1 (first and second instars) larvae and adults caused minimal damage to red clover. Models were developed to predict damage to stipules, buds and flowers when P2 densities range between 0 - 5 larvae per 5 shoot bouquet.

The spatial distribution of eggs, P1 and P2 larvae were shown to be aggregated; aggregation decreased with each succeeding developmental stage. Optimal sample plans, based on aggregation, were developed for eggs, P1, and P2 larvae. These sample plans may be used for surveys and population studies.

Baythroid and Furadan were found to provide effective control of larvae and adults.

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1 INTRODUCTION

The lesser clover leaf weevil (LCLW) (Hypera nigrirostris (Fabr.)) belongs to the family Curculionidae. This family, which includes beetles that are commonly referred too as weevils or snout beetles, is the largest of all insect families. There are about 60,000 described species that belong to this family (Gillott, 1980). Almost all members are phytophagous and many are serious pests (Borror et al., 1981).

The genus Hypera is composed of five species: the alfalfa weevil, H. postica (Gyllenhal), the Egyptian alfalfa weevil, H. brunneipennis (Boheman), the clover head weevil, H. meles (Fabr.), the clover leaf weevil, H. punctata (Fabr.), and the lesser clover leaf weevil (LCLW), H. nigrirostris (Fabr.). As is apparent from their common names, all members of this genus feed on legume crops (Davidson and Lyon, 1979).

1.1 The lesser clover leaf weevil (LCLW)

1.1.1 World Distribution of LCLW

The LCLW has been reported from Russia, western Asia Minor, northern Africa, Japan, Europe (including Britain, Norway, Finland, and Italy), U.S.A. and Canada (Webster, 1909; Blatchley and Leng, 1916; MacNay, 1958; Markkula and Tinnila, 1956; Craig, 1973; Watanabe, 1979). The first report of LCLW in North America was in Massachusetts in 1873-74, though this species probably occurred in limited numbers long before its discovery (Webster, 1909). Schwarz (1908, cited from Webster, 1909) noted that this

species had always been common in eastern North America (ranging from New England to Minnesota). He stated that LCLW was either circumpolar or introduced to North America long ago. Rockwood (1920) suggested the source for the LCLW population located in the Pacific Northwest differed from the eastern North American population. He reported that two parasites of LCLW, Dibrachoides dynastes (Foerster) and Bathyplectes exiguus (Gravenhorst), were present in the Pacific Northwest; but were not reported in eastern North America. In Canada, LCLW has been reported from Newfoundland, Prince Edward Island, Nova Scotia, New Brunswick, Quebec, Ontario, and British Columbia (MacNay, 1958). The first report of LCLW in Saskatchewan was in 1985 (Harris, 1986).

1.1.2 Biology of LCLW

The biology of LCLW has been studied in Russia, northern Europe, U.S.A., and eastern Canada (Herrick and Detwiler, 1919; Hudson and Wood, 1924; Glushchenko, 1955; Markkula and Tinnila, 1956; Sechriest and Treece, 1963). The species overwinters in the adult stage. In spring, adults become active, mate, and lay eggs on host plants. There are four larval instars and pupation occurs within a loosely spun cocoon (Detwiler, 1923; Markkula and Tinnila, 1956). The species is univoltine over much of its range, though an incomplete second generation has been reported in southern areas of the U.S.A (Sechriest and Treece, 1963).

1.1.3 Parasites and Pathogens of LCLW

Webster (1909) identified Anisia spp. (Tachinidae) and Bracon spp. (Braconidae) as parasitoids of larval LCLW in Washington D.C.. Dibrachoides dynastes (Foerster) (Pteromalidae) and Bathyplectes exigua (Gravenhorst) (Ichneumonidae) were reported to be parasitoids of LCLW in northwestern U.S.A. (Rockwood, 1920). B. exigua and a species of Microbracon parasitized LCLW in the state of New York (Detwiler, 1923). B. exiguus and two braconids, Bracon mellitor (Say) and B. tenuiceps (Muesebeck) were parasitoids of LCLW in Ohio (Sechriest and Treece, 1963). Microctonus aethiopoides (Braconidae) is a parasitoid of adult LCLW (Krombein et al., 1979). No egg parasites have been reported. H.E. Bisdee (Biosystematic Research Institute, Ottawa) has confirmed that B. exigua and B. exiguus are the same species (personal communication).

There have been two reports of fungal pathogens associated with LCLW. Webster (1909) felt that Empusa (Entomophthora) sphaerosperma, a fungus that attacks pupae, would provide sufficient control of LCLW because it was an effective control agent of Phytonomus punctatus (Hypera punctata). Rockwood (1951) reported a Hyphomycetous fungus, Beauveria, to be associated with LCLW.

1.2 Host Plants of LCLW

Primary host plants include true clovers, Trifolium spp., particularly red clover, T. pratense (L.), though LCLW has been reported to feed on alfalfa (Medicago sativa) (L.), yellow sweet clover (Melilotus officinalis) (Lam.), white sweet clover (M. alba), (Desr.) and trefoil (Lotus corniculatus) (L.) (Titus, 1911; Hudson and Wood, 1924; Hastings and Pepper, 1949; Sechriest and Treece, 1963). In free choice tests, LCLW larvae preferred red clover, though extensive feeding occurred on alsike (T. hybridum) (L.), and white clover (T. repens) (L.) (Markkula and Tinnila, 1956). They reported that larvae developed to adults from eggs laid on red, alsike, zigzag and white clovers; however, larvae transferred to trefoil and alfalfa died within a few days. Clover species with morphological features such as large stipules and flowerheads appear to be more acceptable to weevils than hosts that lack these structures (Sechriest, 1963).

1.2.1 Red Clover (Trifolium pratense)

Red clover is a biennial crop grown for both seed and forage (Duke, 1981). Red clover is also valuable to growers in terms of increased soil fertility through nitrogen fixation and improved soil structure. In Saskatchewan, red clover is grown in the northeastern agricultural areas. Approximately 20,000 acres of single-cut red clover are grown in Saskatchewan (for seed) (K. Stoner, personal communication). When grown for seed, red clover

is seeded with a companion crop, usually a cereal or canola. In the year of seeding, red clover produces vegetative growth, and the companion crop is harvested. In the following year the first crop of red clover seed is harvested; this is referred to as first year red clover. Occasionally, a seed crop is harvested in the third year (second year red clover).

Red clover seed is a valuable export to the U.S.A. and Europe. In Canada, 2.9 million Kg of single cut red clover seed (pedigreed) were produced annually (five year average for the period of 1981-1985); Alberta was the largest producer, followed by Saskatchewan (700,000 Kg) (Plant Health and Plant Products Directorate - July 2, 1987). This value underestimates total red clover production because 98.8% of single-cut red clover was common rather than pedigreed seed (1988). Export markets for Saskatchewan (1987) were primarily to United States (1.65 million Kg), though small amounts were sold to Italy and the United Kingdom (Statistics Canada, Exports by Commodities, 1987).

1.2.2 Damage to Red Clover by LCLW

The LCLW has been reported to cause damage to red clover in Finland, U.S.A, and Canada (Fletcher, 1884; Detwiler, 1923; and Hudson and Wood, 1924; Markkula and Tinnila, 1956). In North America, this species is one of the most destructive pests of red clover (Metcalf et al., 1962). Both larvae and adults cause damage and the species is more destructive to red clover than the

clover leaf weevil, Phytonomus punctatus (H. punctata) (Webster, 1909; Markkula and Tinnila, 1956; Sechriest and Treece, 1963). Adults feed on shoots, leaves, stipules, buds and flowerheads (Detwiler, 1923; Metcalf et al., 1962 and Sechriest, 1963). Adults cause economic damage by feeding on stems that results in lodging of flowerheads (Tippins, 1958). Larvae, feed on shoots, stipules, buds, and flowerheads, and are responsible for most damage to red clover (Detwiler, 1923; Elliott, 1952; Markkula and Tinnila, 1956).

1.3 Sampling

Knowledge of the spatial distribution of insect populations is important for understanding the population ecology of the species being considered. Sample pattern, and the number of samples collected are based upon spatial distribution. Sample plans are designed to provide an accurate, precise and cost efficient method of gathering information about the population(s) in question.

1.3.1 Spatial Distribution of Insect Populations

Southwood (1978) defined dispersion (or spatial distribution) as the description of the pattern of the distribution of animals in space. Knowledge of insect distribution is important for three reasons. First,

distributions define tendencies of the population under study; distributions may be related to theories of growth, or spread of insect populations. Second, selection of statistical analysis procedures is dependent upon the distribution of the population; suitable transformations cannot be chosen until the distribution of the insect population has been defined. Third, population distribution is required for the development of sampling techniques.

Spatial pattern of insect populations can be divided into three broad categories. Populations described by regular pattern are often referred to as under-dispersed and are a result of mutual repulsion. Contagious or over-dispersed spatial pattern is a result of mutual attraction that results in aggregation. Random distribution occurs when members of the population are independent of each other.

Mathematical models may be used to explain distribution of organisms. Statistical distributions may serve as models. The Poisson series describes randomly distributed individuals in space and the negative binomial distribution describes populations that are contagious. Aggregation indices describe contagious dispersion patterns; these indices have biological meaning.

Natural populations show some degree of aggregation (Morris, 1960); the degree of aggregation may be specific for each species (Taylor, 1961). The observed degree of aggregation may vary depending upon the stage of the insect sampled, the scale of the

habitat sampled or when sampling occurs. Insect species that lay eggs in clusters tend to be less aggregated with increasing maturity. Harcourt (1961b) found that aggregation of imported cabbageworm (Pieris rapae) (L.) larvae tended to decrease with development through the four instars.

1.3.2 Sample Plan Development

Before samples are collected, the sample universe must be defined. The sample universe is the homogenous portion of the habitat that the population occurs (Morris, 1955). Once the universe is defined, samples are collected from the universe. Collection of samples from the whole universe is not practical in terms of cost and statistical analysis. The sample unit is the segment of the sample universe that is to be sampled. Selection of a sample unit is one of the most important decisions when designing a sampling plan. The sample unit may be a biological unit such a whole plant, or part of a plant (branches or leaves) or be defined by a specific shape or size such as a square, circle, square foot or square meter. Where the objective is to assess absolute populations, Morris (1955, p. 245) stated the following must be considered:

1) In order for the sample to be representative of the universe, the sample unit should be of such a nature that all units in the universe have an equal chance of selection.

2) The sample unit must have stability. That is, the number of units available to the insect population must not be affected by changes in growth habits of the plant caused

either by intrinsic factors or by insect damage.

3) The proportion of the insect population using the sample unit as a habitat must remain constant.

4) The sample unit should be reasonably small so that enough units can be examined on a given plot and date to provide and adequate estimate of variance.

5) In absolute population work, where estimates of population per acre are required, the sampling unit must lend itself to quantitative assessments of the total number of units per tree and per acre.

6) [a practical consideration is] the sample unit can be delineated in the field and collected without a serious loss or disturbance to the insect population.

The number of sample units collected is based upon the species spatial distribution, degree of precision required and the cost of collection and examination of samples. Increased sample number leads to an increase in precision; the number of samples collected is limited by the resources available for collection and processing. Sample resources should be allocated to maximize accuracy and precision at a reasonable cost. Morris (1955) states that determination of optimum sample size is dependent upon: 1) The degree of precision required; 2) Optimum number of samples required at each stratum; 3) Effect of changes in population density on optimum sample size and design; and 4) Sampling cost per plot.

Sample size is related to the population density and changes in population density must be taken into account when determining sample size. Sample size is inversely related to population density; this is not surprising if the insect population can be

described by an over-dispersed distribution. Mukerji (1973), Harcourt (1961b), and Harcourt et al. (1974) have shown that more samples must be collected when insect population densities are low or when insect distribution is highly aggregated.

Methods used for sampling insect populations include: unrestricted random sampling, sequential sampling, and stratified random sampling. Unrestricted random sampling requires random location and selection of samples. Sequential sampling is characterized by collection of a flexible number of samples where the total number of samples collected is dependent upon the accumulated results of a series of observations. This type of sampling plan has been widely used for integrated pest management programs, and Kuno (1969) suggested that this technique may be used for absolute estimation of population densities. Stratified random sampling has been the preferred method for ecological studies of insect populations because this method has been shown to provide precise and accurate estimates of populations and minimizes variance (Yates and Finney, 1942; LeRoux and Reimer, 1959; Harcourt, 1961a; Abrahamsen, 1969; Miller et al., 1972; Mukerji, 1973; and Guppy et al., 1975). This method divides or stratifies the sample area into equal size plots. Samples are randomly collected from each plot; variance is minimized by collection of samples so that the whole study area is equally represented.

Guppy et al. (1975) used a stratified random sample plan for population assessment of alfalfa weevil larvae populations. This

sample plan consisted of in four strata (Blocks, plots, quadrats and sample units). Stratified random sample plans similar to this have been used for other developmental stages of the alfalfa weevil (Miller et al., 1972; and Harcourt et al., 1974), Lygus lineolaris (Beauv.) (Mukerji, 1973) the imported cabbage worm (Pieris rapae) (Harcourt, 1961a), wireworms (Yates and Finney, 1942), and Phyllophaga spp. (Guppy and Harcourt, 1973). Each study showed that stratified sampling plans give accurate, precise estimates of population density that are useful for determination of spatial distribution of life stages, mortality due to predation, parasitism, disease and climatic factors could be assessed.

1.3.3 Sampling Methods for LCLW

Sampling methods for LCLW have included random collection of shoots, buds, and flowerheads (Everly, 1953; Markkula and Tinnila, 1956; Sechriest and Treece, 1963; Waters, 1964; Hays, 1965) and sweep netting (Marshall et al., 1949; Hansen and Dorsey, 1957; Tippins, 1958; Markkula and Tinnila, 1956; Sechriest, 1963). These sample plans failed to provide information with regard to spatial distribution and did not attempt to minimize sample variance.

1.4 The LCLW in Northeastern Saskatchewan

As stated, LCLW was first collected in Saskatchewan in 1985.

Craig (1985) reported that every red clover field surveyed in northeastern Saskatchewan was infested by LCLW. LCLW infestations in 1985 reduced seed yields by as much as 80% and caused an estimated loss of 2 million dollars (Harris, 1985). Many fields intended for seed production were ploughed down or used for hay. In 1986, additional fields were ploughed down and very few fields were seeded to red clover.

1.5 Objectives of The Study

LCLW is an important pest of red clover. The occurrence of LCLW has threatened the viability of the red clover seed industry in northeastern Saskatchewan. If a viable red clover seed industry is to be maintained in Saskatchewan, it is essential to know the weevil's life history, determine the effects of biotic and abiotic factors on LCLW population densities, and determine the potential for damage to red clover by LCLW. Furthermore an adequate sample method is required to assess LCLW populations.

In 1986 and 1987 a study of LCLW on red clover seed crops was undertaken with the following objectives in mind:

1) To determine seasonal occurrence, duration and abundance of each of the life stages of LCLW;

2) To identify parasitoids associated with LCLW, measure levels of parasitism, and determine the effect of

parasitoids on LCLW populations;

3) To describe and quantify damage to vegetative and reproductive structures of red clover, and determine relationships between larval densities and damage to stipules, buds, and flowerheads; and

4) To determine the spatial distribution of eggs and larvae and develop an optimal sample plan for estimating density of egg and larval populations of LCLW.

2 LIFE HISTORY OF THE LCLW

2.1 Introduction

In order to gain a better understanding of LCLW biology in western Canada, more specifically Saskatchewan, this study was carried out to investigate the life history of LCLW. The objectives of this study were to determine seasonal occurrence, duration and abundance of each LCLW lifestage on red clover grown for seed in Saskatchewan.

2.2 Materials and Methods

2.2.1 1986

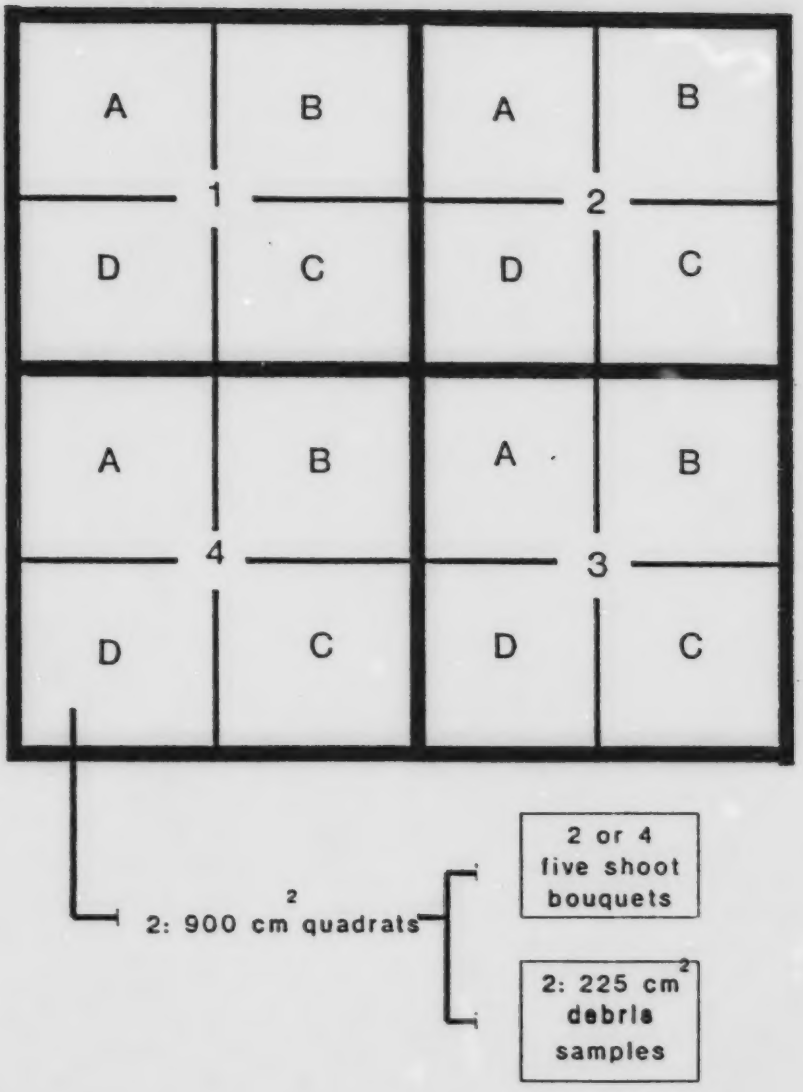
Two fields near Nipawin, Saskatchewan were sampled intensively on a weekly basis from May 25 to August 13. One field was seeded in 1984 (field 1), the other in 1985 (field 2). Both were seeded with barley as a companion crop. Study areas, one in each field, measured 48m x 48m and were divided into six equal sized plots. Larvae and pupae were sampled by collecting all red clover shoots from a quadrat measuring 900cm^2 (30cm x 30cm). Pupae were also collected from debris, consisting of barley chaff and red clover leaves, from the same quadrat. Four quadrat samples were collected from two of six plots. Adults were collected with sweep nets (38cm diameter). One sample unit, consisting of 25 sweeps, was taken in each plot. In early spring adults were sampled using a D-VAC sampler.

To determine wintering sites, soil samples (900cm² to 2.5cm deep) were collected from four fields (including surrounding ditches and tree bluffs) on October 6 and 7, 1986. One field was seeded in 1984 (field 1), two in 1985 (field 3 and 4) and one in 1986 (field 5). Fields 4, 5, and 1 were adjacent. Adult weevils were separated from soil and debris by Berlese funnels and were preserved in 70% alcohol.

2.2.2 1987

In 1987, one field (field 5), near Nipawin, seeded to red clover in 1986 with barley as a companion crop, was sampled on a weekly basis. A stratified sampling plan was employed (Fig. 1). The study area, measuring 48m x 48m, was divided into four square blocks. Each block was divided into four plots of equal size. Two 900cm² (30cm x 30cm) quadrat samples were randomly selected from each of the 16 plots. Two types of sample units (i) five shoot bouquet and ii) 225cm² debris sample) were used. The five-shoot bouquet was collected to estimate egg, larval, and pupal population densities. Two or four bouquets (four bouquets for eggs, two bouquets for larvae and pupae) were collected from each quadrat; 128 (or 64) bouquets were collected on each sampling date. Shoots were cut off at ground level and bagged. In addition to bouquet samples, pupal densities were assessed by collection of four 225cm² (15cm x 15cm) debris samples. Five shoot bouquets were collected from May 3 to August 9; debris samples were collected from June 29 to August 9.

Fig. 1. Stratified sample plan used to sample immature stages of H. nigrirostris.


A
B
A
B
1
2
D
C
D
C
A
B
A
B
4
3
D
C
D
C
2 or 4 five shoot bouquets
2: 900 cm² quadrats
2: 225 cm² debris samples

Sweep nets (38cm diameter) were used to sample adults from May 3 to August 9. One set of 25 sweeps (180°) was taken in each plot.

Each week a measure of stand density was estimated by counting the number of shoots per quadrat.

In both years, samples were returned to the laboratory for processing. Eggs, larvae, and pupae were sorted from shoot and debris samples. First and second instar larvae were separated from third and fourth instars by the color and size of headcapsule, cervical shield and body. Larvae were arranged into two groups: period one (P1) and period two (P2) (after Guppy et al., 1975). P1 larvae included first and second instar larvae; P2 larvae included third and fourth instar larvae. Specimens were stored in 70% alcohol.

Developmental periods were determined by rearing field collected eggs, P1 larvae, P2 larvae and pupae in separate 4.5cm diameter petri dishes in growth cabinets maintained at 22°C and 70% RH, with a 16 hour light: 8 hour dark photoperiod. Width and length of eggs and headcapsules were measured with an ocular microscope micrometer.

Data were analyzed using the statistical program SYSTAT. Shoot results from 1986 were converted to the number per 5 shoots. In both 1986 and 1987 results from debris samples were converted to a five shoot equivalent:

(# pupae per quad) / (# shoots per quad / 5) [2.1]

Temperature and precipitation data were recorded at the Environment Canada weather station at Nipawin, Saskatchewan.

2.3 Results and Discussion

2.3.1 Eggs

Eggs were ellipsoidal and measured .638 +/- 0.009 mm long and 0.369 +/- .009 mm wide (the +/- values reflect 95% confidence intervals). These results agree with those reported by Houghton (1908), Webster (1909), Detwiler (1923), Hudson and Wood (1924), Markkula and Tinnila (1956), and Sechriest and Treece (1963) who reported egg lengths of 0.5-0.64mm and widths of 0.2-0.4mm. Eggs, characterized by fine sculpturing, were white when first laid but became grey 3 or 4 days after oviposition. One day prior to hatching, eggs darkened, and the embryonic headcapsule and body segments became visible.

Eggs were located in stipules (56.9%), stems (35.2%), and leaves (7.9%). These differences were significant ($P < 0.01$). Webster (1909) and Hudson and Wood (1924) found eggs to be located primarily in stipules; Detwiler (1923) and Sechriest and Treece (1963) reported finding eggs in leaves and stipules. Markkula and Tinnila (1956), in glass tube rearings, state that 99.49% of the eggs were situated in leaves; in the field 89% of eggs were located in leaves (Markkula and Tinnila, 1955).

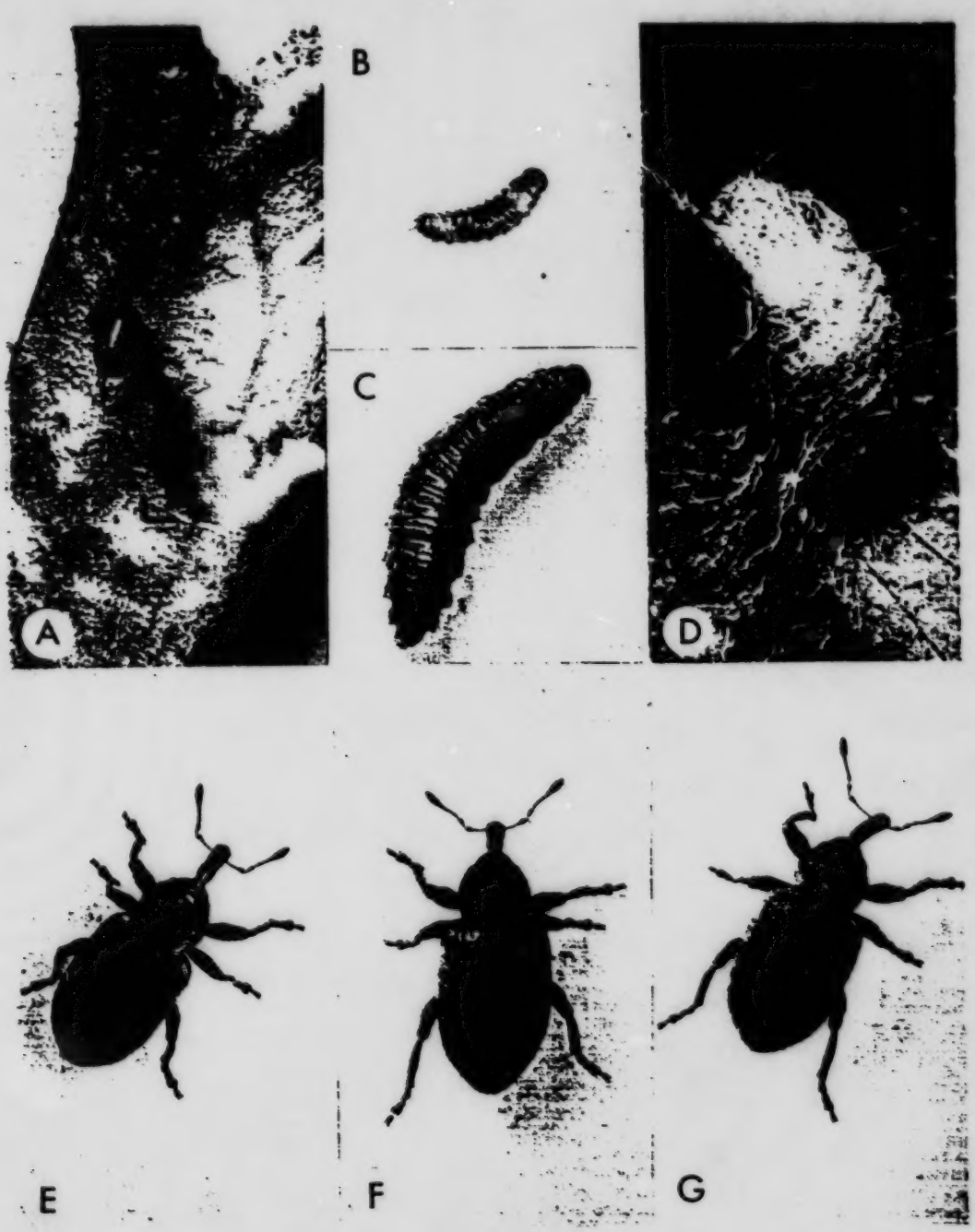
In stems and leaves, oviposition cavities were created by

the female, using her mandibles to cut a slit into the epidermis to form a small a depression in the parenchyma. In stems, eggs often were placed in the pith. Eggs were found on both upper and lower surfaces of leaves. Eggs were laid mostly on the outer side of stipules where the epidermis frequently was separated from parenchyma, allowing females to oviposit eggs without excavating a cavity in the parenchyma (Fig. 2a). In each case, oviposition occurred beneath intact epidermal tissue. The oviposition slit was difficult to observe, even when viewed through a microscope.

It appears, because the epidermis was separated from underlying parenchyma, less effort was required to oviposit eggs in stipules, and that suitable food and cover is situated within the stipule area, it is not surprising that the most eggs were located in stipules. Often, eggs laid in stems were located close to stipules, ensuring food and protection for P1 larvae. It would appear that larvae hatching from eggs oviposited in leaves would have a further distance to travel to locate a suitable environment for feeding and development.

Eggs mostly were found individually although clusters of two, three and four did occur at all sites. Differences were significant between cluster size ($P < 0.01$). Markkula and Tinnila (1955) reported similar results for eggs deposited on the upperside of leaves, though clusters of two were most common on the underside of leaves. They state that in cool years, a

Fig. 2 (a-g). Stages in the lifecycle of H. nigrirostris.
a) egg in a red clover stipule
b) P1 larva
c) P2 larva
d) Pupa on a red clover leaf
e) Overwintered adult
f) newly emerged brown adult
g) new season (green) adult


A
B
C
D
E
F
G

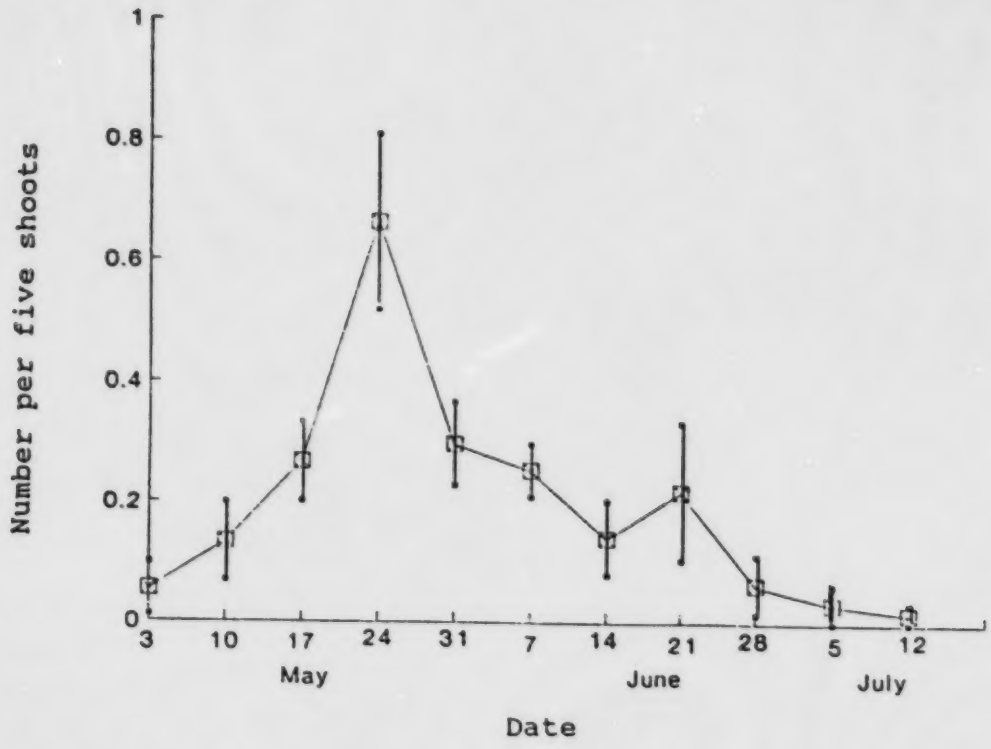
reduction in the absolute number of eggs occurs, and that eggs are laid individually.

Eggs were collected from May 3 to July 13 (1987) (Fig. 3). Oviposition began when the mean daily temperature reached 13.3°C (May 1 - 7), and red clover plants were 6-8cm tall with 3-5 stipules per shoot; no reproductive structures were present at this time. Maximum egg densities occurred on May 25 when red clover shoots were 10cm tall, though lacking buds or flowers. The minimum daily mean temperature required for oviposition was 12°C in Ohio (Sechriest and Treece, 1963) and 15°C in Finland (Markkula and Tinnila, 1956). In the present study, oviposition occurred over a period of 11 weeks. Elsewhere, LCLW oviposition periods vary in duration from 6 to 8 weeks in Finland (Markkula and Tinnila, 1956) and 5 months in Ohio (Sechriest and Treece, 1963).

Eggs reared under growth-cabinet conditions (22°C) hatched in 2-7 days, depending on their developmental state. The incubation period averaged 6.4 days for light eggs, 5.4 days for grey eggs, and 3.3 days for dark eggs. Values for light eggs were less that those reported by Markkula and Tinnila (1956) (8 days at 21°C) and Sechriest and Treece (1963) (7.2 days at 27°C).

Egg-rearing studies showed that 96.8% of the eggs were viable, the remaining eggs showed no development.

Fig. 3. Density (number per five shoot bouquet) of LCLW eggs in 1987 (vertical bars represent standard error)


Number per five shoots
1
0.8
0.6
0.4
0.2
0
3
10
17
24
31
7
14
21
28
5
12
May
June
July
Date

2.3.2 Larvae

Grub-like larvae were white to grey with a prominent headcapsule (Fig. 2b and 2c). Based on measurements of headcapsule width and length, it was determined that LCLW has four larval instars (Table 1). Detwiler (1923) reported the following headcapsule widths (mm): I-0.20, II-0.28, III-0.38 and IV-0.50 and Sechriest and Treece (1963) reported headcapsule widths of (mm): I-0.22, II-0.29, III-0.39, and IV-0.53. The results of this study are marginally higher than those of Detwiler (1923) and similar to those reported by Sechriest and Treece (1963).

First instar larvae were 1 mm long. Their headcapsule and prominent cervical shield were black. Second instar larvae were marginally larger, with a more robust and slightly darker body than first instar larvae. The headcapsule and cervical shield of third instar larvae were dark grey. The cervical shield was not as prominent as in first and second instar larvae. Third instar larvae were 4-5mm in length. The body of fourth instar larvae was yellow to light green, 7mm long with the headcapsule and cervical shield (which was almost indistinguishable) being light brown or tan (Fig. 2b and 2c).

After hatching, larvae moved to stipules, buds or folded leaves to feed. If eggs were laid in stipules, first instar larvae had a very short distance to move to suitable feeding sites that included stipules, buds and flowerheads. Larvae from eggs laid in stems and leaves, moved down stems to stipules, buds

Table 1. Headcapsule widths and lengths (mean +/- 95% confidence interval estimates) (mm) of LCLW larvae.

Instar	Width		Length	
1	0.220	0.005	0.168	0.005
2	0.294	0.004	0.270	0.005
3	0.406	0.006	0.343	0.004
4	0.540	0.005	0.415	0.010

or folded leaves.

Pooled results from 1986 and 1987 (results were not significantly different between years) showed that significantly ($P < 0.01$) more P1 larvae were located in stipules (79.4%), than in buds (15.3%), or flowerheads (5.3%). Sechriest (1963) reported that first instar larvae were quite often located in terminal buds. This was rare in this study because buds were not present until mid June.

Movement between feeding sites usually was minimal for P1 larvae; they often remained at the same location until it became devoid of food. However, if suitable food was in short supply, P1 larvae moved up the shoot to new feeding sites. Generally, only one larva was observed per stipule, bud or folded leaf, although two or three larvae were observed to occupy one feeding site.

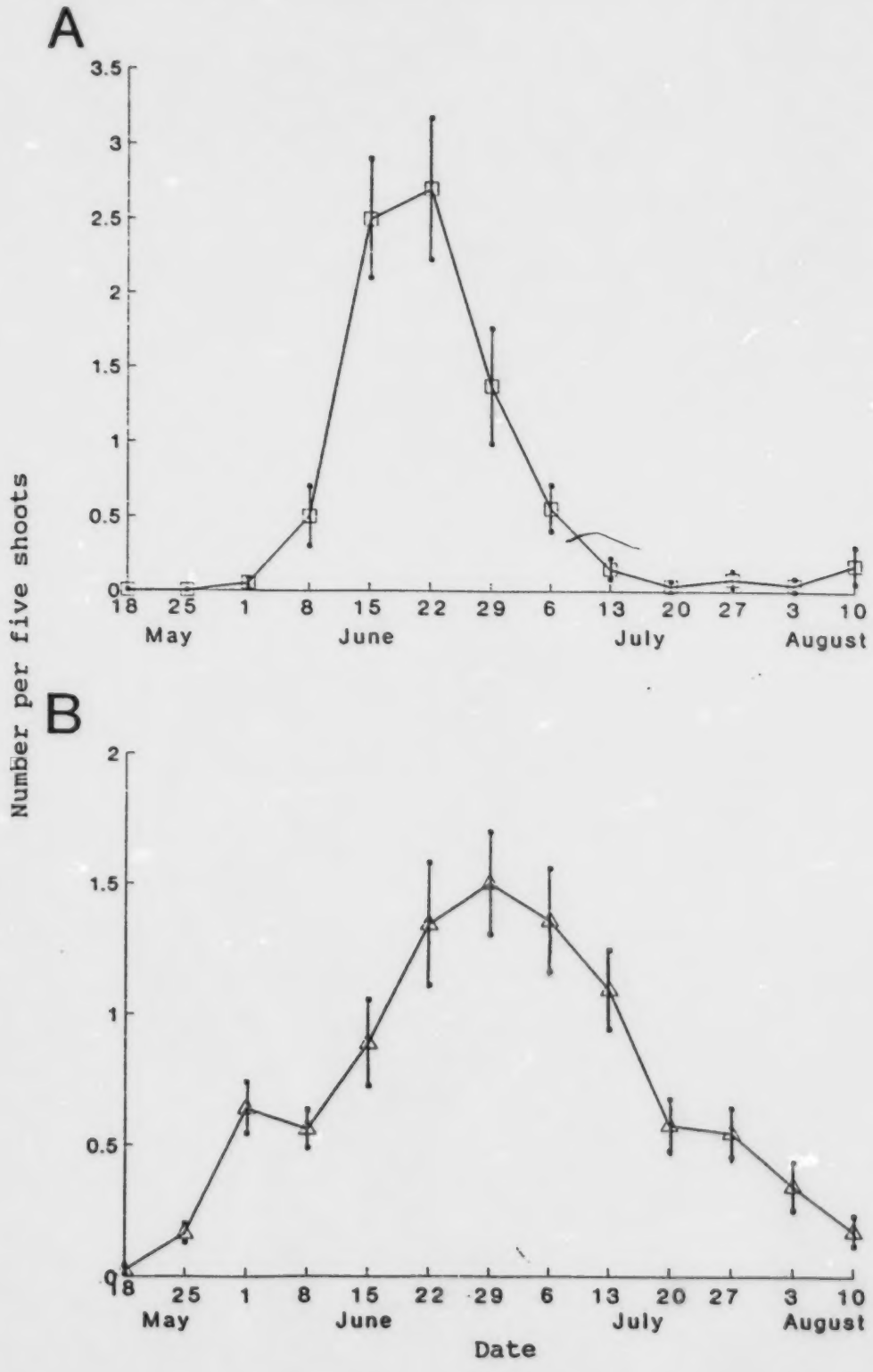
In 1986, P1 larvae were collected from the first week of June, when red clover shoots were 10-15cm tall with very few buds, until the last sample date in August (Fig. 4a). Densities of P1 larvae peaked on June 18; clover was 30-35cm tall and in full bloom.

In 1987, P1 larvae were collected from mid May until late August (Fig. 4b). In mid May red clover was approximately 10cm tall with four or five stipules. No reproductive structures were present. Peak densities of P1 larvae occurred during the week of June 29 when red clover shoots were 50-55 cm tall with two to four buds, and flowers were beginning to appear (1 week prior to peak

bud occurrence).

Often, there was not more than one P1 larva per stem. On June 29, 1987 (date of peak P1 density) there were significantly ($P < 0.01$) more cases of one P1 larvae per shoot (79.5%) than two (16.4%), three (2.7%) or four (1.4%) per shoot (for shoots with larvae present). On July 26, (date of peak P2 density), significantly ($P < 0.01$) more P2 larvae occurred individually on shoots (91.1%) than two (5.8%) or three (3.1%) per shoot (for shoots with larvae present). These values differ from those of Markkula and Tinnila (1956) who report (for shoots with larvae present) 57.4% of shoots had one larva, 22.2% had two larvae, 4.5% had three larvae and 15.9% had 4 larvae (all instars). They state the number of larvae found simultaneously per shoot is a function of larval densities; increasing densities cause increased occurrence of multiple numbers of larvae per stem. In Finland, larval densities were between 2.5 and 3.0 larvae per five shoots. In contrast, in this study, peak larval densities ranged from 3.0-3.5 larvae per five shoot bouquet and higher densities showed a greater occurrence of individual larvae per stem. It would appear, that at these densities, some other

Fig. 4 (a, b). Density (number per five shoot bouquet) of LCLW P1 larvae in 1986 (a) and 1987 (b) (vertical bars represent standard error).


A
B
Number per five shoots
3.5
3
2.5
2
1.5
1
0.5
0
2
1.5
1
0.5
0
18 25 1 8 15 22 29 6 13 20 27 3 10
May June July August
Date

factor besides density, has an effect on the number of larvae per stem.

Because of their size, P2 larvae fed in stipules, buds and flowers; these larvae were usually too large to feed in folded leaves. Significantly ($P < 0.05$) more P2 larvae were located in stipules and flowerheads than buds (Table 2). P2 larvae often were located in stipules (near the base of the shoot) during June and early July and in buds and flowerheads by the second week in July. There does not appear to be a preference for stipules or flowerheads, the differences being due to relative abundance of each. A greater number of P2 larvae were located in buds and flowerheads in 1986 than in 1987. This is because reproductive structures occurred earlier in 1986 than in 1987. This result agrees with Markkula and Tinnila (1956) who report that in 1953 and 1954 (warm summer - larvae occurred prior to appearance of buds and flowerheads) greater than 90% of larvae (all instars) fed in stipules and in 1955 (cool summer - larvae occurred when fields were in peak bloom) 63% of larvae were located in buds and flowerheads.

Movement between stipules was common, as P2 larvae fed in one to five stipules during their development. Movement between stipules was most often in an upward direction. This observation differs from that made by Sechriest and Treece (1963) who reported that larvae move down the stem in search of new feeding sites. Sometimes, P2 larvae tunnelled into stems near stipules. When in flowerheads, P2 larvae generally remained there. Larvae fed in a

Table 2. Comparison of the percentage of LCLW P2 larvae located on stipules, buds and flowerheads (percentage of total).

Year	Stipules	Buds	Flowerheads
1986*	34.0a	22.1b	43.9a
1987*	45.8a	15.7b	38.5a

*Means within each row followed by the same letter are not significantly different (Duncan multiple-range test, P=0.05)

spiralling fashion, as they moved from the base to the top of the bud or flowerhead.

Fourth instar larvae moved to suitable pupation sites after completion of feeding. This generally involved movement down the shoot to lower stipules, leaves or the ground, or they remained within the flowerhead where they had fed.

In 1986, P2 larvae were collected from early June until the last sampling date in August with peak populations occurring on June 20 (Fig. 5a). Field conditions were similar to those described for P1 larval collections. In 1987, P2 larvae were collected from May 31 until August 9 (Fig. 5b). In early June, red clover was 10-16cm tall, and buds had begun to appear. Densities of P2 larvae were highest in mid July. At this time, shoots were 70-90cm tall with and 50% of flowers were mature.

Under growth-cabinet conditions (22°C), the larval period (first to fourth instar) was 17-18 days. Sechriest and Treece reported a larval period (27°C) of 13.5 days. In Finland, for tube-reared larvae, the larval period was 14-20 days (temperature range was 17.1-20.4°C) (Markkula and Tinnila, 1956).

2.3.3 Pupae

When mature, fourth instar larvae constructed delicate, lacy, ellipsoidal, partially transparent cocoons 4mm long and 2.5mm wide (Fig. 2d). Fourth instar larvae entered a resting stage (prepupa) before molting into a pupa that initially was light green or yellow, later darkening to brown.

Cocoons were located both on shoots and in ground debris. In 1986, significantly ($P < 0.05$) more pupae were located in debris (60.9%) than on shoots (39.1%). However, in 1987, significantly ($P < 0.01$) more pupae were collected from shoots (80.2%) than debris (19.8%). Cocoons were constructed in many locations on the plant including stipules, leaves and flowerheads (Table 3). Lower stipules, usually dry and brown, were preferred to upper stipules; in 1986, 73.4% of pupae in stipules were found in lower stipules. Cocoons were constructed on both the underside and upperside of leaves. Dry brown leaves usually were preferred over fresh green leaves. Pupation sites were located on all areas of the flowerhead. Pupae occurred in equal numbers on both blooming flowerheads and flowerheads in which seed had set.

In both 1986 and 1987, pupae were collected from late June to the end of the sampling period in August (Fig. 6a and 6b). In late June (1986) red clover fields were in full bloom and plants were 35-40cm tall. During the same time, in 1987, red clover fields had shoots that were 50-55cm tall with only a few flowerheads. In both years peak pupal densities occurred when the red clover was in full bloom.

Under growth-cabinet conditions, the pupal period was 5-6 days.

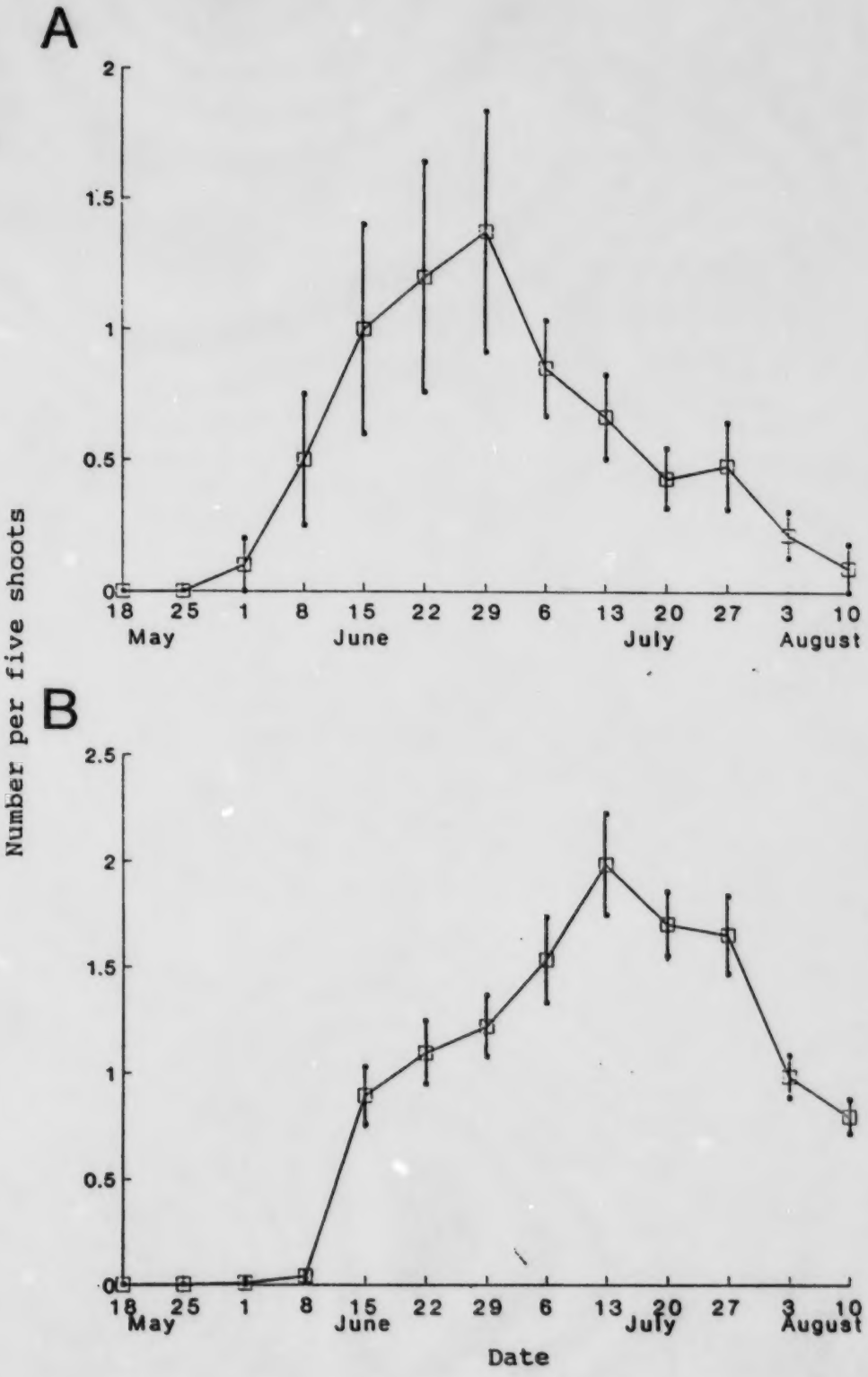

A
B
Number per five shoots
2
1.5
1
0.5
0
2.5
18 25 1 8 15 22 29 6 13 20 27 3 10
May June July August
Date

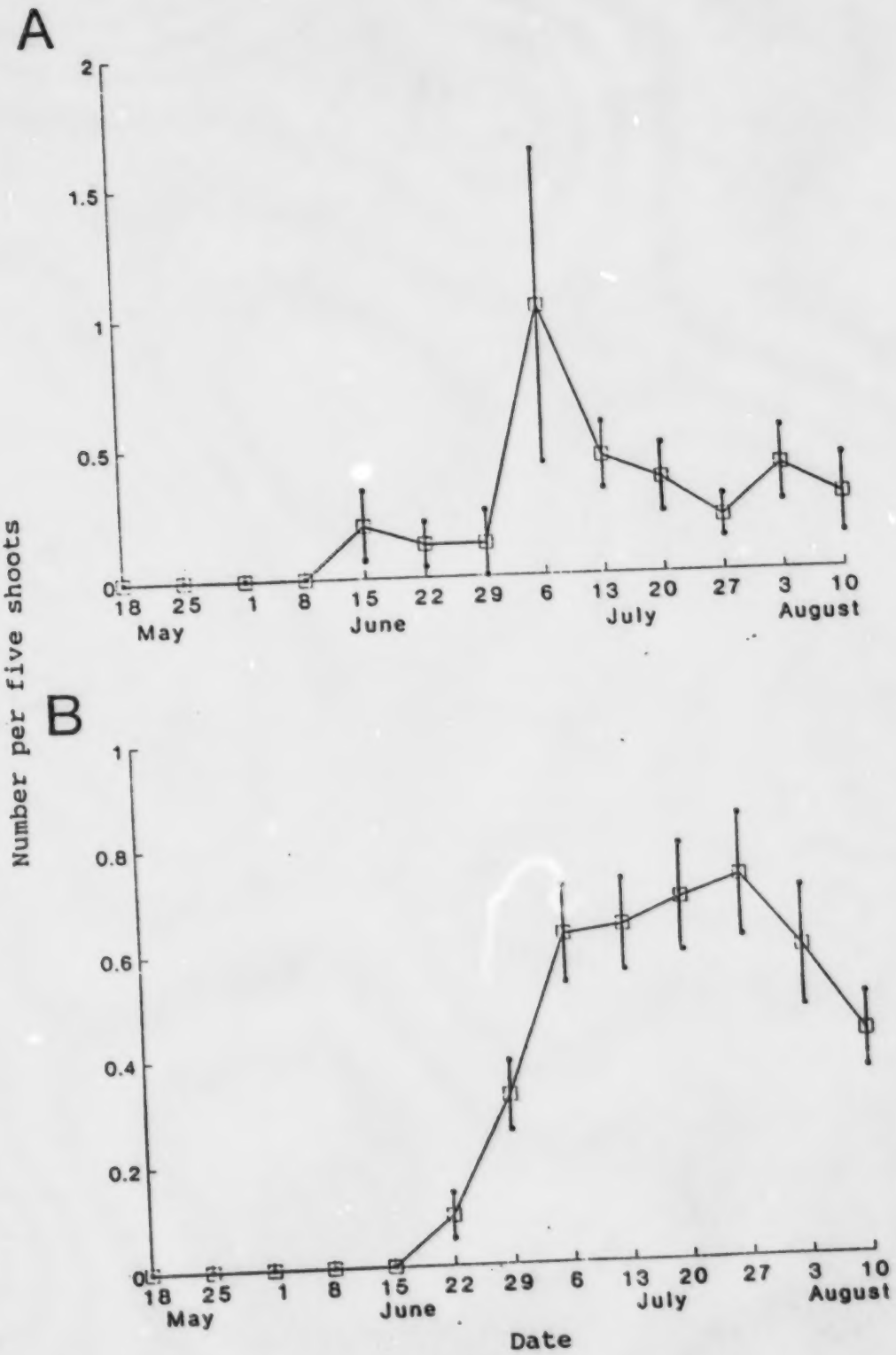
Fig. 5 (a, b). Density (number per five shoot bouquet) of LCLW P2 larvae in 1986 (a) and 1987 (b) (vertical bars represent standard error).

Table 3. Location of LCLW pupae on red clover shoots (percentage of total).

Year	Stipules	Flowers	Leaves	Other
1986*	81.9a	6.6b	3.3b	8.2b
1987*	43.0a	13.0b	44.0a	-

*Means within each row followed by the same letter are not significantly different (Duncan multiple-range test, P=0.05)

Fig. 6 (a, b). Density (number per five shoot bouquet) of LCLW pupae in 1986 (a) and 1987 (b) (vertical bars represent standard error). Results from debris samples were converted to a five shoot equivalent using eq. [2.1].


A
B
Number per five shoots
2
1.5
1
0.5
0
1
0.8
0.6
0.4
0.2
0
18 25 1 8 15 22 29 6 13 20 27 3 10
May
June
July
August
Date

2.3.4 Adults

Overwintered adults were blue-green or occasionally nearly black. Adults were light brown or tan shortly after eclosion. Within a few days, the elytra and pronotum began to appear green. Approximately 1 week after eclosion, adults became bright green. These differences made it possible to distinguish between overwintered, newly emerged, and late summer adults (Fig. 2e, 2f, and 2g).

In October 1986, soil samples were collected from four fields to determine wintering sites of LCLW. Fields 5, 4, and 1 were adjacent. The mean number of adults (per quadrat) was 0.32, 2.45, 0.33 and 0.00 for fields 1, 3, 4, and 5 respectively. Adults appeared to winter in sites in the field where debris had accumulated. The distribution of these adults varied, apparently being related to their density. Adult distribution in field 3 appeared aggregated. The number ranged from 0-15 adults per sample. Adult distribution in fields 4 and 1, which had one-tenth the density of 3, appeared to be distributed randomly. On occasion, adults were collected from the bases of trees and within grass in areas surrounding fields.

Adults began to move to other red clover fields in spring. In 1987, movement was prior to the first week in May because signs of adult feeding were noted on May 3 in field 5. Adults fed, mated and began oviposition in early May. At this time, adults were located at the base of red clover plants where they fed on stipules, young (unfolded) leaves and stems. Newly

emerged brown and green adults were located throughout the plant. In early August, adults moved to the lower areas of the plant and fed on young leaves that resulted from secondary growth. In Wisconsin, LCLW adults have been shown to enter a summer diapause (Litsinger and Apple, 1984).

In both years, overwintered adults were observed in red clover fields during early May as the crop was beginning new growth. Red clover plants were too short to sample with sweep nets. D-VAC sampling in early June (1986) failed to effectively sample adults. At this time, presence of adults was inferred from feeding holes on leaves. In June (both years), adult densities were approximately one adult per 25 sweeps (Fig. 7); no new season adults were present (Table 4). Adult densities increased above one per 25 sweeps in early July when newly emerged adults began to appear. During the rest of the summer, new season adults were prevalent.

2.3.5 Duration of Complete Development

Growth cabinet studies show that the mean total development period, from eggs to adults, was 28.6 days at 22°C. 1987 field results range from 40-65 days. In both 1986 and 1987, peak adult densities occurred on July 20. Using a developmental threshold of 10°C (developmental threshold for Hypera postica (Guppy and Mukerji, 1974), adult populations peaked in 418.2 and 428.2 degree days respectively. Sechriest and Treece (1963) report a developmental period of 27.8 days at 27°C, which translates to

498 degree days. In Saskatchewan, the LCLW has one generation per year.

Fig. 7. Density (number per 25 sweeps) of LCLW adults in 1986 (a) and 1987 (b) (vertical bars represent standard error).

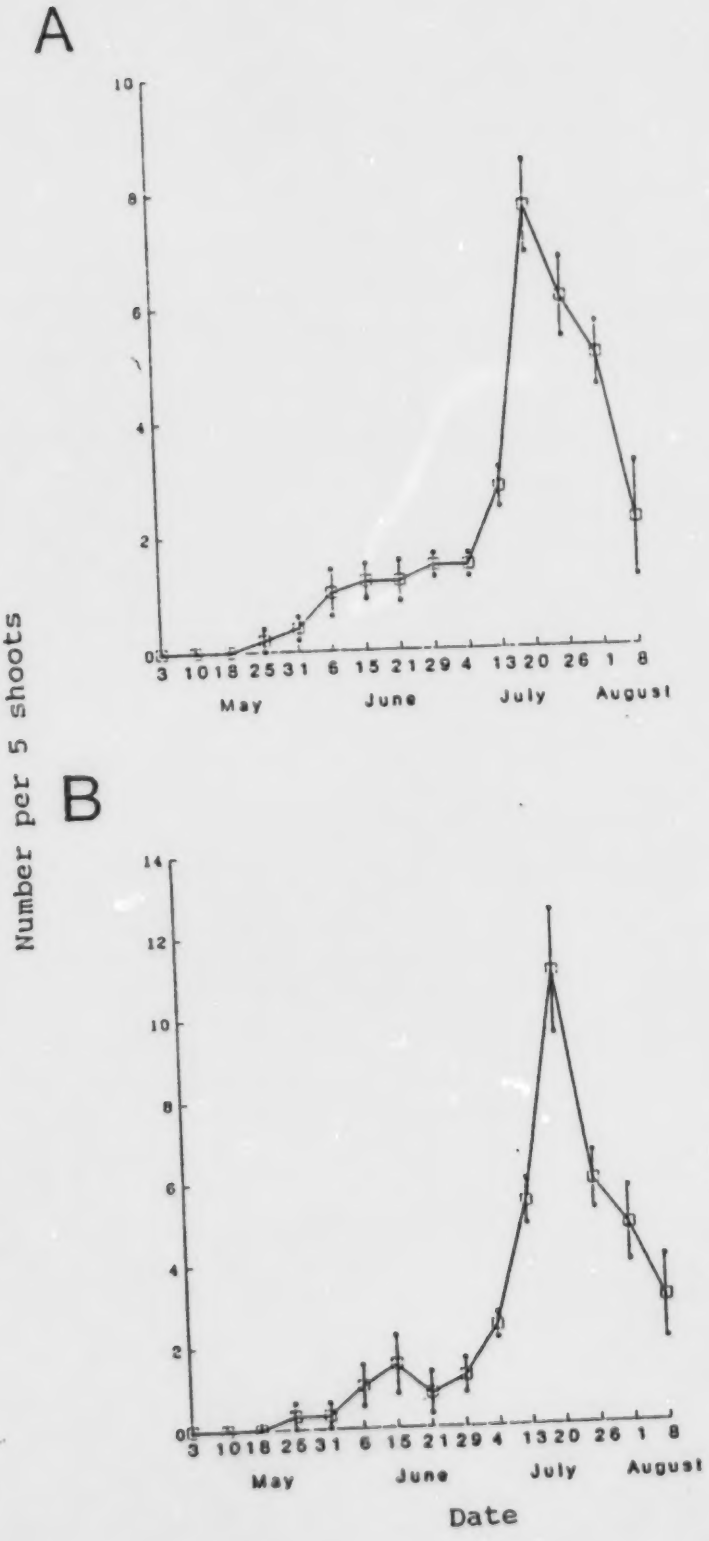

A
B
Number per 5 shoots
0
2
4
6
8
10
12
14
3 10 18 25 31 6 15 21 29 4 13 20 26 1 8
May
June
July
August
Date

Table 4. Occurrence and proportion of overwintered (OW), newly emerged brown (Brn), and newly emerged green (Summer) LCLW adults (% of total) on various sampling dates in 1986 and 1987.

Year	Date	OW	Brn	Summer
1986	June 2	100.0	-	-
	June 26	100.0	-	-
	July 9	5.0	95.0	-
	July 14	5.0	61.6	33.4
	July 22	0.2	61.0	38.8
	Aug. 13	-	25.0	75.0
1987	May 25	100.0	-	-
	June 15	100.0	-	-
	June 29	88.2	11.8	-
	July 13	19.0	71.4	9.6
	July 26	2.9	62.1	35.0
	Aug. 9	-	30.8	69.2

3 PARASITISM OF Hypera nigrirostris

3.1 Introduction

An understanding of LCLW population dynamics requires knowledge of natural control agents associated with LCLW.

In 1985, B. exiguus was associated with outbreak populations of LCLW near Nipawin, Saskatchewan. The objectives of this study were to identify parasitoids associated with LCLW, measure levels of parasitism, and determine the impact of parasitoids on LCLW populations in Saskatchewan.

3.2 Materials and Methods

In 1986 and 1987 field collected LCLW adults (new season) were reared in clear plastic containers (9cm x 9cm x 9cm) to assess adult parasitism. Specimens were maintained at 22°C, 60-70% RH and a phctoperiod of 16 hours light and 8 hours dark. The weevils were fed red clover shoots and maintained for a period of 30 days.

In 1987, studies were carried out to determine which developmental stages of LCLW were parasitized. LCLW eggs, P1 and P2 larvae, and pupae were collected from fields on a weekly basis and reared individually in petri dishes (4.5 cm dia.) containing moist filter paper; the dishes were placed in growth cabinets (similar conditions to those described above). Larvae were fed

red clover buds.

Parasitoids were counted after emergence from the host. Specimens were sent to the Biosystematics Research Institute (Ottawa) for identification.

In 1986 and 1987 rates of field parasitism were estimated each week by counting parasitized larvae and pupae sorted from red clover shoots (see section 2.2). B. exiguus was identified by the presence of a B. exiguus cocoon within a LCLW cocoon, or by dissection of P2 larvae that appeared to be parasitized by this parasitoid; LCLW larvae appeared distended when a B. exiguus larva was present. B. tenuiceps was identified by presence of its cocoon near a dead P2 larva, or by the presence of P2 larvae that were killed by this parasitoid (larvae were collapsed). Other parasitoids were identified by their presence within LCLW cocoons.

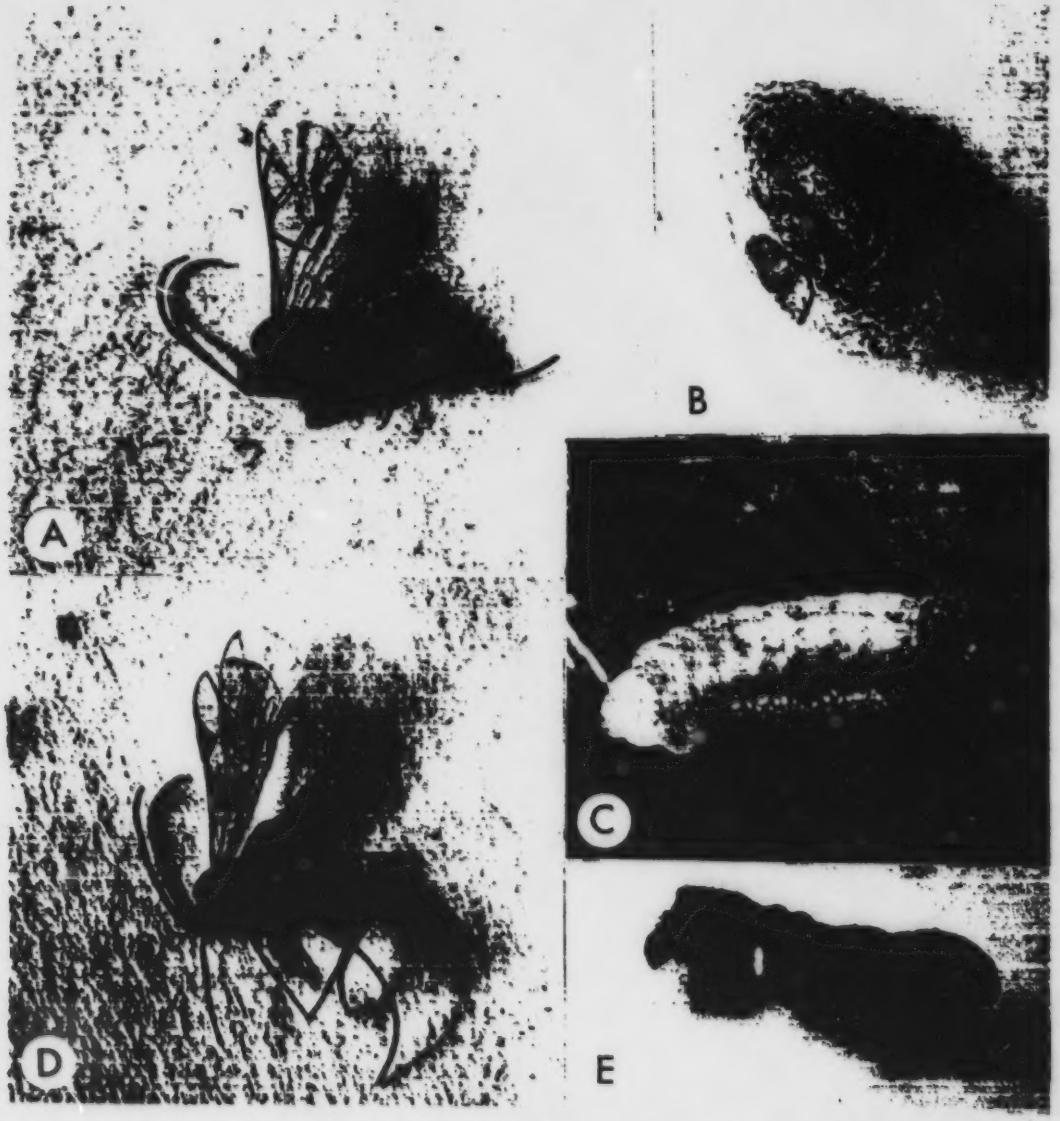
3.3 Results and Discussion

Hymenopterous parasitoids were reared only from LCLW larvae and pupae and included one Braconidae (Bracon tenuiceps), three Ichneumonidae (Bathyplectes exiguus, Scambus (Scambus) decorus (Walley), and Gelis sp.), and four Pteromalidae (Dibrachoides dynastes, Chlorocytus sp. and two species of Habrocytus sp.).

3.3.1 Bracon tenuiceps (Braconidae)

Bracon tenuiceps was associated with P2 larvae (Fig. 8d). Often one pupal cocoon was located close to a LCLW cadaver that appeared shrivelled (Fig. 8e). Clausen (1940) reported that in

Fig. 8. B. exiguus and B. tenuiceps
a) B. exiguus adult
b) B. exiguus cocoon within LCLW cocoon
c) B. exiguus larva (pink) emerging from LCLW (P2) larva
(note LCLW headcapsule and exoskeleton)
d) B. tenuiceps adult
e) LCLW larval (P2) remains after emergence of B. tenuiceps.


A
B
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many braconid species, females paralyze their prey by inserting venom and feed upon body fluids from the host.

Though this species was recorded in 1986, it was not as abundant as in 1987, when it was first observed on July 13 (peak P2 density) and was present until the last sampling date. B. tenuiceps were associated with decreasing P2 populations (Fig. 9). The declining P2 densities were explained by parasitism by B. tenuiceps and pupation. In 1987, B. tenuiceps caused significantly ($P < 0.05$) more mortality of P2 larvae than any of the other parasitoid species; 23.8% of P2 larvae were parasitized by this species. This species kills the weevil during the developmental stage that causes greatest damage to red clover.

B. tenuiceps parasitized significantly ($P < 0.01$) more larvae that were located on flowerheads (86.4%) than on stipules (6.8%) or leaves (6.8%). However, when the total P2 population was considered, P2 larvae were located in flowerheads and stipules in similar numbers. The data suggest that B. tenuiceps were selecting P2 larvae in flowerheads over larvae in other locations, possibly because they were not able to parasitize larvae located in stipules as easily as larvae located in flowerheads. This may explain the low density of B. tenuiceps in 1986 when P2 larvae were most often located in stipules. It is likely that in years when P2 larvae occur predominantly in stipules, such as 1986, B. tenuiceps may have limited potential to control LCLW populations.

Fig. 9. LCLW P2 larval densities (number of larvae per five shoot bouquet) (line) and weekly parasitism (%) by Bracon tenuiceps (bars).

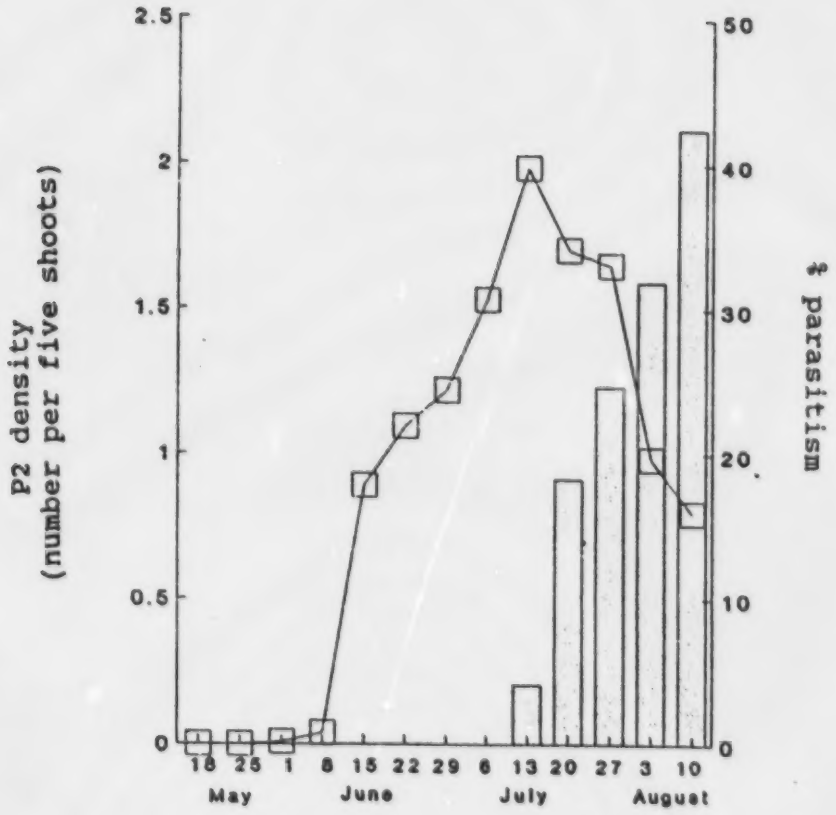


Fig. 9. LCLW P2 larval densities (number of larvae per five shoot bouquet (line) and parasitism (%) by B. tenuiceps (bars).

3.3.2 Bathyplectes exiguus (Ichneumonidae)

B. exiguus caused significantly ($P < 0.05$) more pupal mortality than S. decorus, D. dynastes or Gelis sp. In 1986 and 1987 B. exiguus was collected from late June until the last sampling date in mid August. Parasitism rates were 35.8% and 27.3% in 1986 and 1987 respectively. Table 5 shows weekly parasitism rates for 1986 and 1987. Rockwood (1920) stated that approximately 50% of LCLW cocoons were parasitized by B. exiguus and Detwiler (1923) reported that this species was very abundant in New York state.

B. exiguus females (Fig. 8a) primarily oviposited in P2 larvae; only 2.1% of P1 larvae were parasitized by this parasitoid. This species often emerged from host pupae, though they occasionally emerged from P2 larvae (Fig. 8c). The parasitoid's cocoon, that was located in the LCLW pupal cocoon, was brown with a white band and measured 2.5 - 3.0mm in length (Fig. 8b). Females did not paralyze their hosts; though parasitized larvae, particularly fourth instar, appeared less mobile than non-parasitized larvae.

Significantly ($P < 0.05$) more pupae parasitized by B. exiguus were located on shoots than debris in both 1986 (61.4% (shoots) and 21.2% (debris)) and 1987 (37.1% (shoots) and 22.5% (debris)). The data suggest that, due to reduced movements, parasitized P2 larvae do not move to pupation sites on debris in the same numbers as non-parasitized larvae. Significantly ($P < 0.05$) more parasitized pupae were located on stipules than on

Table 5. Weekly parasitism (%) of LCLW pupae by B. exiguus in 1986 and 1987.

	1986	1987
June 29	28.5	20.0
July 4	16.0	26.0
July 13	40.1	13.9
July 20	42.9	29.2
July 26	50.0	27.2
Aug. 1	43.5	46.1
Aug. 10	28.6	42.3

leaves or flowerheads (Table 6). However, there was no significant difference between locations of parasitized and non-parasitized LCLW pupae on shoots. B. exiguus appears able to parasitize LCLW P2 larvae on all parts of the plant. Though P2 larvae parasitized by B. exiguus continue to feed, they may feed less than non-parasitized larvae. Armbrust et al. (1970) have shown that H. postica larvae parasitized by Bathyplectes curculionis fed less than non-parasitized larvae. They conclude that B. curculionis was beneficial in two ways: 1) reduced food consumption by larvae results in economic gain in the same year and 2) long term gain results from reduction of the next weevil generation. It is possible that parasitism of P2 larvae by B. exiguus may produce similar benefits.

3.3.3 Chlorocytus sp. and Habrocytus sp. (Pteromalidae)

In 1987, Chlorocytus sp. and Habrocytus spp. were found within cocoons of B. exiguus. These species were collected from early July until the mid August (last sampling date) (Table 7). In 1987, 39.4% of B. exiguus were hyperparasitized by these Pteromalids. Hyperparasitoids emerged after cocoon formation by B. exiguus. Hyperparasitism would decrease B. exiguus populations in the following year and possibly the potential for B. exiguus to control LCLW populations.

Table 6. Location on shoots (% of total) of LCLW pupae parasitized by B. exiguus in 1986 and 1987.

Location	1986	1987
Stipule*	89.8a	48.9a
Leaf*	3.5b	19.3b
Flowerhead*	6.7b	31.8b

* means within each column followed by the same letter are not significantly different (Duncan multiple-range test, P=0.05)

3.3.4 D. dynastes (Pteromalidae)

Four specimens of D. dynastes were collected from a LCLW cocoon on July 4, 1987. On July 26, 1987, five individuals of this species were collected from a LCLW cocoon that also contained the remains of a B. exiguus cocoon. This was the first record of D. dynastes in Saskatchewan. This species was introduced from Europe to control the alfalfa weevil, Hypera postica (Gyll.), in 1911-13. G. Gibson (personal communication) states that chalcidoids are notorious for their ability to be either a primary or secondary parasitoid and it would not be surprising for D. dynastes to be functioning as a hyperparasitoid. Fisher et al (1961) report that D. dynastes is an ectoparasite that attacks late instar H. postica larvae, particularly those within cocoons. Rockwood (1920) reported "fair" numbers of this species were attacking cocoons of LCLW.

3.3.5 Gelis sp. (Ichneumonidae)

Gelis sp. parasitized P2 larvae and constructed white cocoons within weevil cocoons. This species was collected between June 29 and August 9 (1987). Krombein et al. (1979) state that members of this genus are often hyperparasites that attack cocoons of Braconidae and Ichneumonidae. Caldwell and Wilson (1975) report Gelis sp. to be a hyperparasite of B. curculionis, a parasitoid of H. postica. They report this hyperparasite attacked pupal B. curculionis. In this study, on

Table 7. Weekly hyperparasitism rates (%) of B. exiguus by Habrocytus spp. and Chlorocytus sp. in 1987.

and	n (number of B. exiguus cocoons)	% hyperparasitism (Habrocytus Chlorocytus)
July 4	5	20
July 13	4	25
July 26	10	40
August 1	9	33
August 9	5	80

only one occasion (n=11) was Gelis sp. associated with a B. exiguus cocoon (from field-collected LCLW specimens reared in petri dishes). In the other 10 cases adult Gelis sp. emerged from LCLW cocoons. This species may be a parasitoid of LCLW or it may parasitize B. exiguus after it has emerged from the LCLW and prior to formation of its cocoon.

3.3.6 S. decorus (Ichneumonidae)

On June 20, 1987, one S. decorus adult was recovered from a LCLW that was collected as a P1 larva and pupated. This specimen constructed a transparent cocoon within the host cocoon.

In summary, B. tenuiceps and B. exiguus were the most abundant parasitoids associated with LCLW. In both cases, parasitism of P2 larvae resulted in increased mortality and possibly reduced damage potential to red clover; these two parasites appear to be important factors for control of weevil populations. Latheef et al. (1979) state, in a study using lifetable analysis, that one of the largest alfalfa weevil K factors was larval mortality due to Bathyplectes curculionis.

It is unusual for parasitoids of an introduced species to become common soon after appearance of the host in a new region (Rockwood, 1920). B. exiguus is specific for H. nigrirostris (Rockwood, 1920) and furthermore, other species of the genus Hypera are not present in northeastern Saskatchewan, therefore it appears improbable that parasitoids shifted from another species

to LCLW. The diversity and abundance of parasitoids and hyperparasites associated with LCLW in Saskatchewan, suggests that this weevil species has been in this province for many years (the first red clover was grown in northeastern Saskatchewan in the 1940's - K. Stoner, personal communication).

Considering that LCLW has not been reported prior to 1985, when it was associated with severe crop losses, it appears that the parasitoid complex, in combination with abiotic factors, may be capable of maintaining weevil populations at low densities in most years.

4 FEEDING AND DAMAGE TO RED CLOVER BY LCLW

4.1 Introduction

Previous studies of LCLW damage to red clover have been primarily descriptive (Detwiler, 1923; and Hudson and Wood, 1924; Markkula and Tinnila, 1956; Sechriest and Treece, 1963); few have attempted to determine relationships between larval densities and damage to red clover (Everly, 1953).

The objectives of this study were to describe and quantify damage to vegetative and reproductive structures of red clover, and determine relationships between larval densities and damage to stipules, buds, and flowerheads.

4.2 Materials and Methods

Damage assessments were made weekly. In 1986, all shoots were removed from a 900cm² quadrat and shoots were divided into 5 shoot bouquets (refer to section 2.2.1). In 1987, 64 five-shoot bouquets were collected using a stratified sample plan (refer to section 2.2.2). In 1986, the number of damaged stipules, buds and flowerheads were counted. In 1987, the number of damaged and non-damaged stipules (this included shoots, young leaves and reproductive structures that were enclosed by the stipule), buds, and flowerheads were counted. Any bud or flowerhead showing damage was counted, regardless of the extent of damage. Plant density (number of shoots per 900cm²), shoot height, and the

number of sidestems per shoot were measured.

Data from 1987 were used to quantify relationships between larval populations and damage to stipules, buds, and flowerheads. Weekly means for counts of larvae and plant structures were used.

Larval populations were measured by counting the number of larvae (P1 and P2 larvae were counted separately) per five-shoot bouquet. Adult populations were assessed using a sweep net (38cm diameter). One set of 25 sweeps was taken in each plot.

4.3 Results and Discussion

Adults were observed feeding on shoots, leaves, and flowerheads. In early spring, overwintered adults fed on young unfolded leaves and stems. Characteristic holes through both sides of the leaflet resulted from this type of feeding. Damage to red clover leaves appeared to have little effect on plant growth or flower production. Tippins (1958) states that adult feeding on stems resulted in lodging; this was not observed in this study. New season adults fed on mature leaves on upper portions of shoots and on secondary growth at the bases of plants. These adults also were observed feeding on florets within flowerheads; occasionally up to 50% of the florets within a flowerhead were destroyed. New season adults occasionally fed on petioles that support flowerheads and caused complete loss of flowerheads. It is possible that heavy infestations of new season adults could cause a decrease in seed yield by this type of feeding (Detwiler, 1923).

Larvae fed on stipules, shoots, leaves, buds and flowerheads. Feeding on developing tissues within stipules often resulted in destruction of potential shoots, leaves, buds and flowers (Fig. 10a and 10b).

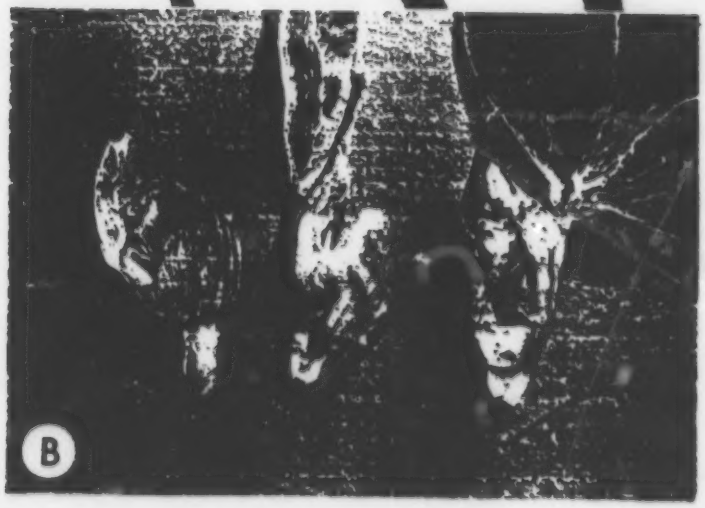
Damage to buds ranged from 30-100%; values were between 10-75% for flowerheads. Larvae fed in a spiral pattern, moving from the base of the reproductive structure to the top. Within buds and flowerheads, 10-100% of tissues were damaged; P2 larvae caused a greater amount of damage to buds and flowerheads than P1 larvae.

Larval densities were similar in 1986 and 1987 (Figs. 4a, 4b). In 1986, larvae fed primarily in stipules; in 1987 larvae fed initially in stipules and shifted to flowerheads in July.

The number of damaged stipules per five shoot bouquet was significantly ($P < 0.01$) greater in 1987 (12.5) than 1986 (4.9). However, it was observed that the amount of damage per stipule was greater in 1986 than 1987 and it appeared, from observations in 1986, that severe damage to stipules may result in loss of potential buds and flowerheads. However, in 1987, damage to stipules did not cause a significant reduction in the number of buds or flowerheads. Significant bud and flower loss, resulting from damaged stipules, would appear to be dependent on the degree of damage occurring within stipules; the degree of stipule damage was minor in 1987. The following equation explained 89.1% of the

Fig. 10 (a, b). Damage stems, stipules and buds by LCLW larvae.
a) stems and stipules (note the non damaged shoot with emerging bud (right)).
b) buds

A


B

variance associated with damage to stipules (DSTIP) by P2 larvae in 1987:

$$DSTIP = 0.29 + 6.99 * P2 \qquad [4.1]$$

Fig. 11 illustrates this relationship.

The number of damaged buds per five shoot bouquet was significantly ($P < 0.01$) greater in 1986 (5.5) than in 1987 (1.8). In 1987, up to 56% of buds were damaged (weekly values). In Ohio, the number of damaged buds was as high as 63% (Sechriest and Treece, 1963). The following equation explains 78.8% of the variance associated with damage to buds (DBUD) by P2 larvae in 1987:

$$DBUD = -2.70 + 3.36 * P2 \qquad [4.2]$$

Fig. 12 illustrates this relationship. In this study, the damage potential for buds was approximately 50% lower than values obtained in Indiana, where 1.6 larvae per 5 shoot bouquet caused 5.9 to 6.7 damaged buds per five shoots (Everly, 1953). The discrepancy may be explained by differences in plant phenology and occurrence of P2 larvae. In Everly's study, red clover may have been in the bud stage when larvae were in greatest abundance; in 1987, peak densities of P2 larvae occurred after occurrence of buds.

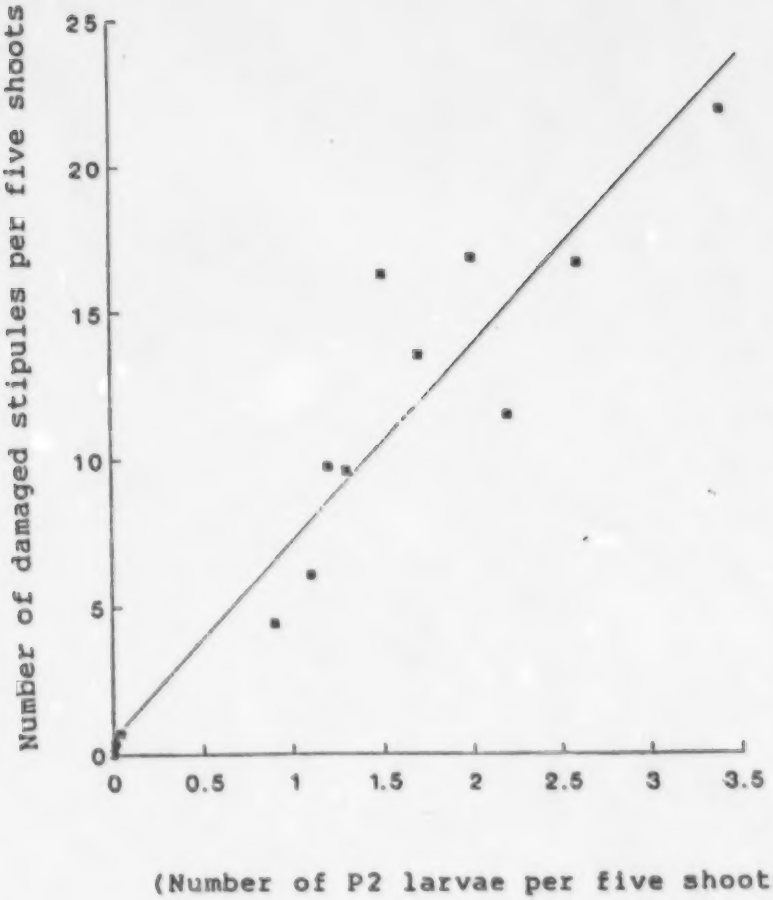


Fig. 11. Linear relationship between P2 density (number per five shoots) and the number of damaged stipules (DSTIP) (number per five shoots) in 1987.

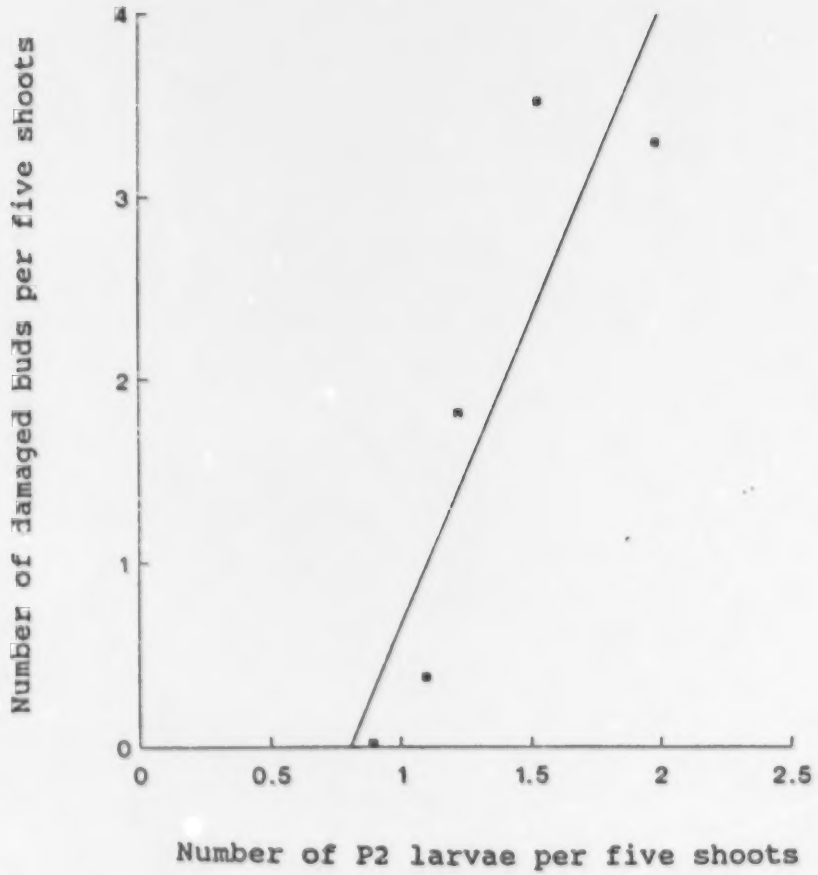


Fig. 12. Linear relationship between P2 density (number per five shoots) and the number of damaged buds (DBUD) (number per five shoots) in 1987.

The number of damaged flowerheads per five shoot bouquet was not significantly different between years (0.7 and 0.6 in 1986 and 1987 respectively). Examination of flowerheads indicated that usually less than 50% of florets were damaged. The following equation explains 93.0% of the variance associated with damage to flowerheads (DFH) by P2 larvae (1987):

$$DFH = -1.72 + 1.50 * P2 \qquad [4.3]$$

Fig. 13 shows this relationship.

Koehler and Pimental (1973) reported that third and fourth instar H. postica larvae were responsible for 95% of plant consumption during larval development. In this study, data suggest that P2 larvae are a major cause of damage to stipules, buds and flowerheads; this can result in decreased seed yield. Examination of slopes for the three regression lines (eqs. [4.1], [4.2], and [4.3]) indicates that P2 larvae have a greater potential to damage stipules, followed by buds and flowerheads. LCLW population densities in 1987 resulted in 20% damage to stipules, buds and flowerheads (seasonal mean). This damage probably did not cause economic loss of red clover seed. However, densities of three P2 larvae (or greater) per five shoot bouquet have the potential to cause greater than 50% damage to buds and flowerheads.

At least three additional factors must be considered when analyzing the damage potential of LCLW larvae on red clover:plant

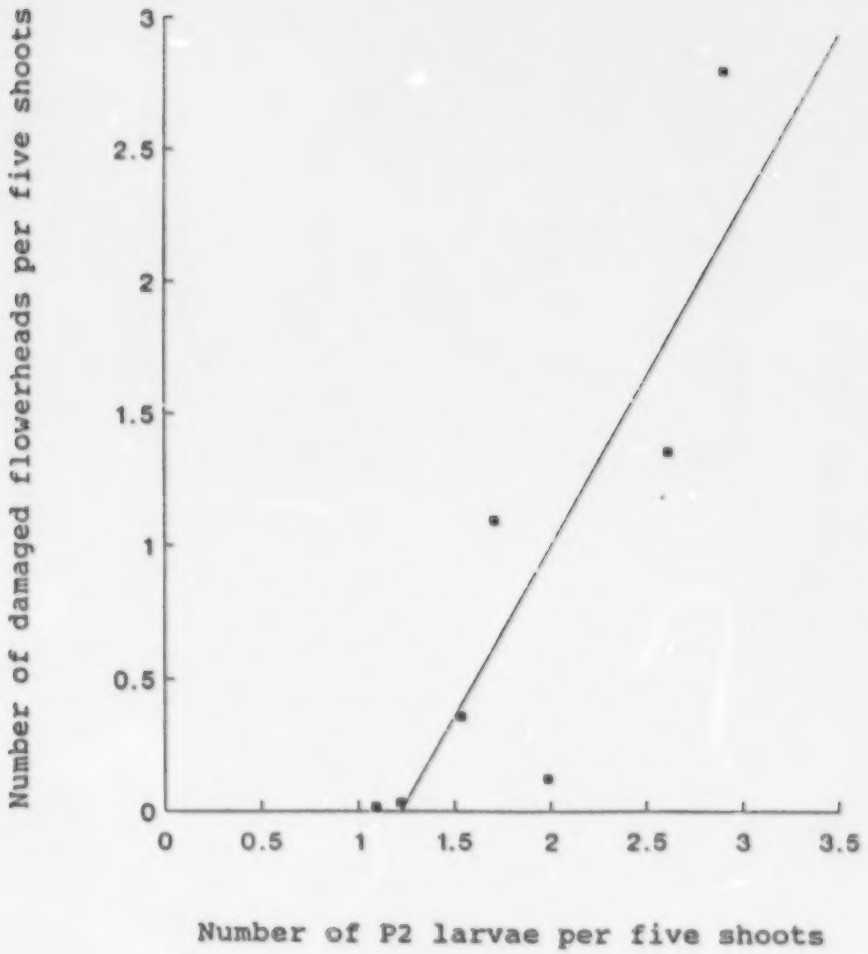


Fig. 13. Linear relationship between P2 density (number per five shoots) and the number of damaged flowerheads (DFH) (number per five shoots) in 1987.

growth rate, plant phenological stage and the level of parasitism by B. exiguus and B. tenuiceps.

Red clover crops entered the bloom stage 1 to 2 weeks earlier in 1986 than in 1987; however, plants were larger, and produced more stipules and reproductive structures in 1987. The differences in plant phenology and growth may be explained by differences in temperature and precipitation between the two years. The cumulative amount of precipitation from April to July inclusive was 214.4 and 362.8 mm in 1986 and 1987 respectively; mean monthly temperatures were generally lower in 1986 than in 1987. Weather (in terms of precipitation and temperature) in 1987 is closer to long term weather patterns; plant phenology is probably more representative in 1987. It is possible that when stressed (i.e. water stress, or stress due to weevil damage), red clover reduces vegetative growth and produces reproductive structures sooner than when under conditions of suitable moisture. Koehler and Pimentel (1973) have shown that alfalfa was able to compensate for feeding by weevils. Thus in 1986, P2 larvae were near peak densities as red clover was beginning to bud and that the most damaging stage, P2 larvae, were present on red clover when crops were susceptible to damage. In 1987, when most P2 feeding occurred prior to appearance of reproductive structures, damaged shoots showed no decrease in buds or flowers.

Parasitism may have an impact on the amount of P2 larval feeding. Parasitism by B. tenuiceps shortens the feeding period of the most damaging larval stage (P2 larva). Although P2 larvae

parasitized by B. exiguus feed and then construct a pupal cocoon, it is probable that parasitized larvae feed less than non parasitized larvae; Armbrust et al., (1970) reported that H. postica larvae (third and fourth instars) parasitized by Bathyplectes curculionis fed less than non-parasitized larvae. Both B. tenuiceps and B. exiguus may reduce the potential for a portion of the larval population to cause damage.

5 DETERMINATION OF SPATIAL DISTRIBUTION AND DEVELOPMENT OF OPTIMUM SAMPLE PLAN FOR LCLW EGGS, P1 AND P2 LARVAE

5.1 Introduction

Quantitative studies of insect populations require sample plans that provide an accurate measure of how insect populations function within their habitat. It is obvious that larger sample sizes provide a more reliable estimate of the population being sampled. However, when the cost of sample collection is considered, collection of unnecessarily large sample numbers is unwise. Optimum sample size is defined as the smallest sample size that assures the desired reliability of the estimate (Karandinos, 1976).

Sample plans are designed to provide accurate, precise and cost-efficient methods of gathering information about the population in question. Many sample plans have used statistical (frequency) distributions, such as the negative binomial distribution, to describe aggregation (Harcourt, 1961b; Mukerji, 1973 and Guppy et al., 1975). However, statistical distributions have no biological component and may yield different estimates of aggregation with varying population densities (Taylor, 1984). Aggregation indices are based on population mean and variance and indices such as Taylor's Power Law (Taylor, 1961) are characteristic of the species in question. Sample techniques, using Taylor's power law, have been developed for insect

populations (Regniere and Sanders, 1983; Mukerji et al., 1988).

Quantitative sample plans are lacking for LCLW eggs and larvae. The objectives of this study were to determine the spatial distribution of eggs and larvae (P1 and P2) and to develop a sample plan for estimating density of egg and larval populations of LCLW.

5.2 Materials and Methods

The data for analysis of spatial distribution and sample plan development were taken from the samples collected for the lifehistory study (Sec. 2.2). The number of eggs, and P1 and P2 larvae was estimated on 10, 23, and 21 occasions (over 2 years), respectively.

Three sample units were considered as possible units for assessing egg, larval and pupal populations: bud/flowerhead, branch, and stem. Selection criteria for the sample unit was based on the criteria defined by Morris (1955). It would be extremely difficult to sample all buds and flowers equally; young buds are located deep within bracts. Furthermore, buds and flowers are not present for the duration of the sampling period; buds are present early in the season, flowers are found later in the season. Sidestem (branch samples) number varies depending on seeding rate, soil moisture and possibly insect damage. The third choice, the shoot, more precisely a five shoot bouquet satisfied all six criteria, and this was chosen as the sample unit.

Population means ($\bar{X}$) represent the number of individuals per sample unit. This unit, selected after the criteria of Morris (1955), is small, easy to collect, stable, and allows for conversion to absolute population estimates.

The relationship between mean and variance was required for determination of required sample sizes. Taylor (1961) stated that variance (S^2) was related to the mean ($\bar{X}$) by a power law; the variance is proportional to the fractional power of the mean:

$$S^2 = aX^b \qquad [5.1]$$

where a is a sampling or computing factor and b is the index of aggregation. The regression of variance as a function of the mean after log-log transformation yields the following relationship:

$$\log_{10} S^2 = \log_{10} a + b \log_{10} \bar{X} \qquad [5.2]$$

The sample size (n_o) required to achieve a given degree of precision based on estimates of the mean and variance is obtained by:

$$n_o = \frac{t_{\alpha/2}\, S}{C\, X}^2 \qquad [5.3]$$

where $t_{\alpha/2}$ is the standard deviate corresponding to the desired probability level (Student's t) and C is the constant proportion of the mean based on the half width of the $(1 - \alpha)$ confidence interval.

5.3 Results and Discussion

5.3.1 Spatial Distribution

The regression of $\log_{10}S^2$ as a function of $\log_{10}\bar{X}$ per five shoot bouquet gave the following results:

for eggs: $\log_{10}S^2 = 1.37 + 1.26 \log_{10}\bar{X}$ ($r^2 = 0.945$) [5.4]

for P1 larvae: $\log_{10}S^2 = 0.32 + 1.12 \log_{10}\bar{X}$ ($r^2 = 0.964$) [5.5]

for P2 larvae: $\log_{10}S^2 = 0.22 + 1.09 \log_{10}\bar{X}$ ($r^2 = 0.982$) [5.6]

The intercepts were significantly ($P < 0.001$) greater than zero and the slopes were significantly ($P < 0.001$) greater than unity. The data are illustrated in Figs. 14, 15, and 16. Taylor's aggregation index (b) is useful for describing spatial distribution because the index is independent of the sample number or sample size, and is stable with changing population densities (Taylor, 1984). Values of b greater than 1 suggest aggregation; the degree of aggregation increases with increasing b values. The distribution of each stage was aggregated, though the degree of aggregation decreased with succeeding developmental stages. Furthermore, at very low densities (0.003 and 0.01 for P1 and P2 larvae, respectively) aggregation decreases and the larval distribution becomes random; the line describing the Poisson distribution overlaps the line for the regression of variance as a function of the mean (Figs. 15 and 16). Similar observations were made by Regniere and Sanders (1983) for spruce budworm larvae (Choristoneura fumiferana). The degree of

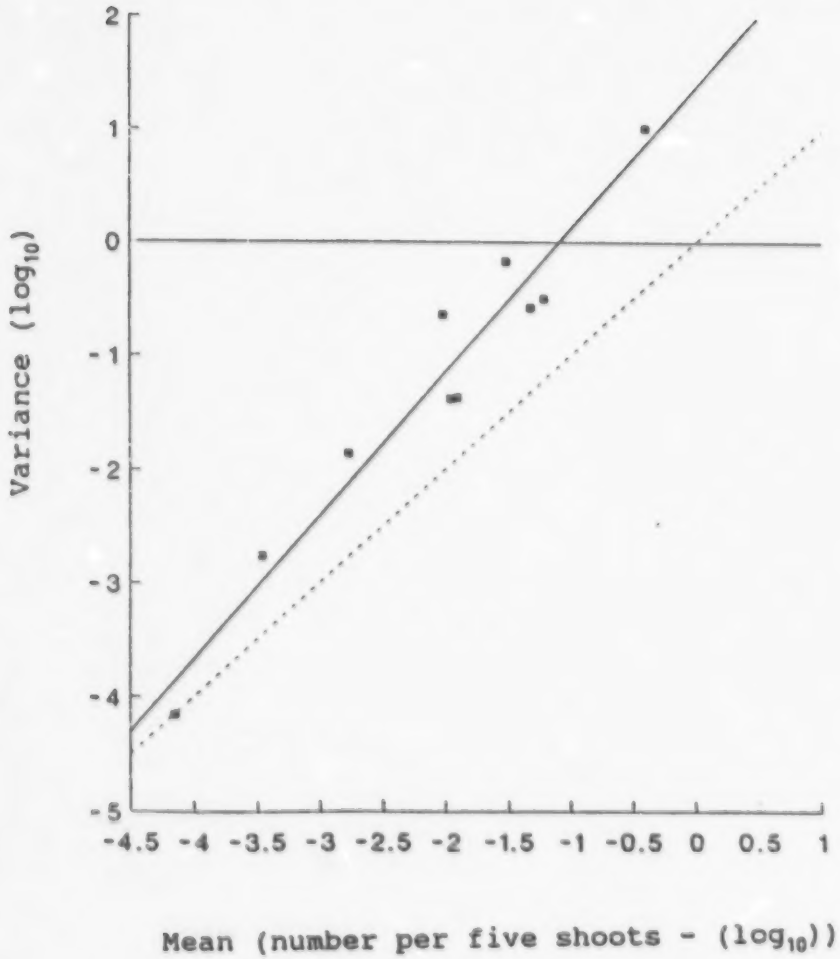


Fig. 14. Relationship between sample mean and variance for egg counts of LCLW (based on eq. [5.4]). The solid line (___) represents Taylor's Power Law, and the dashed line (---) represents the Poisson distribution.

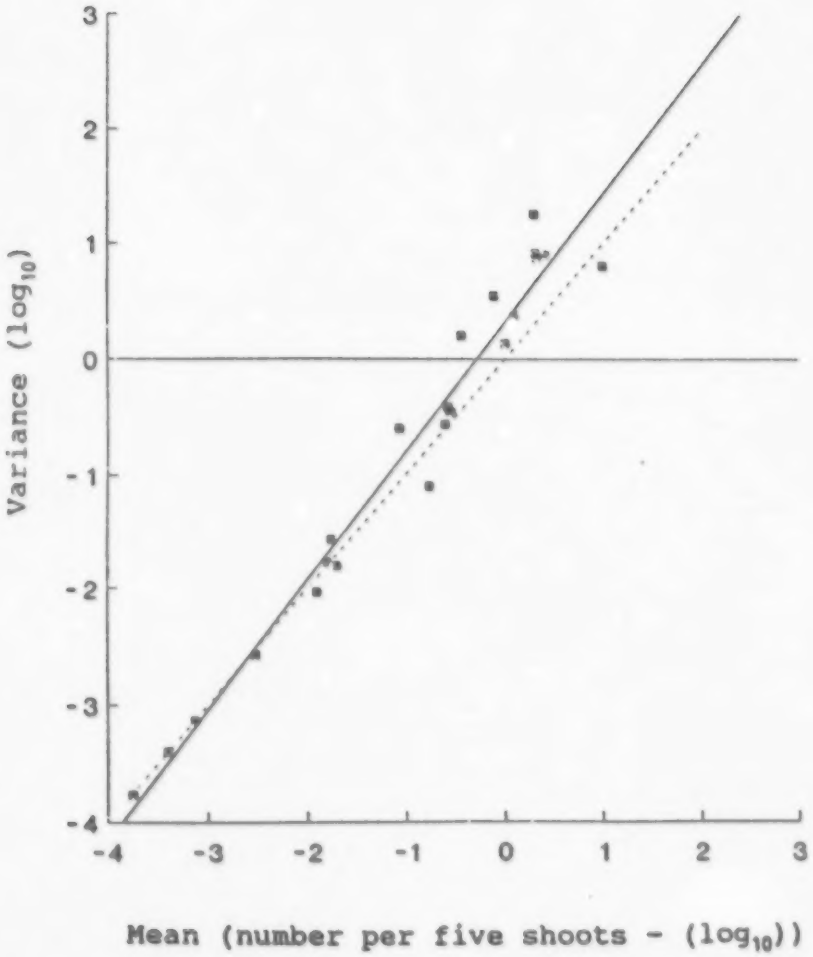


Fig. 15. Relationship between sample mean and variance for P1 larval counts of LCLW (based on eq. [6.5]). The solid line (___) represents Taylor's Power Law, and the dashed line (---) represents the Poisson distribution.

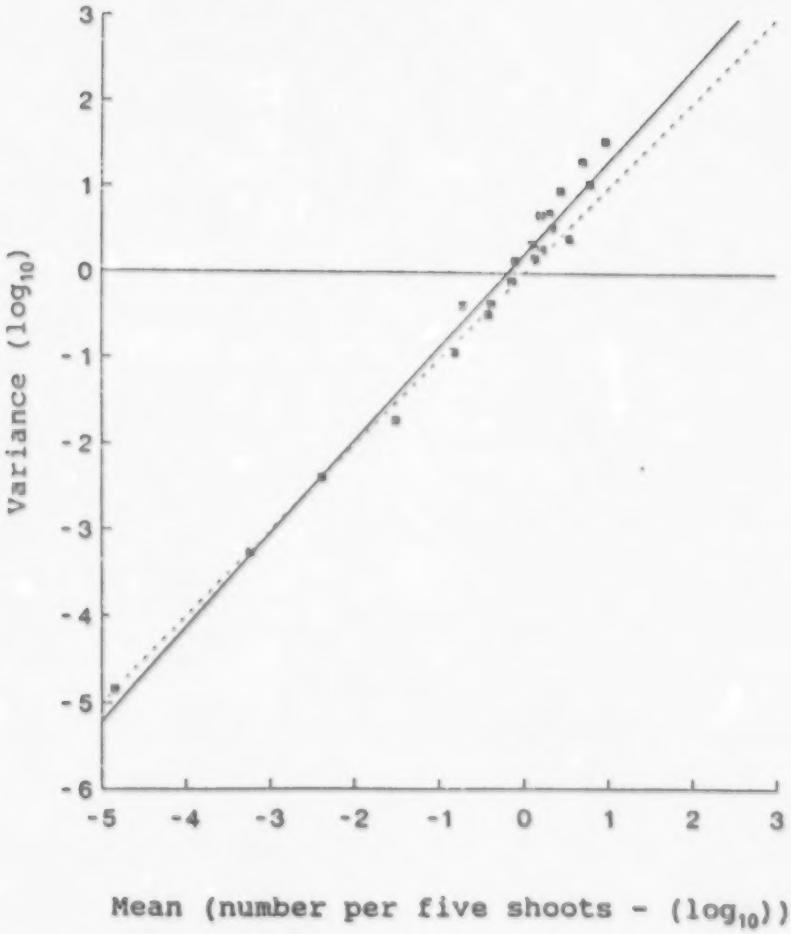


Fig. 16. Relationship between sample mean and variance for P2 larval counts of LCLW (based on eq. [5.6]). The solid line (___) represents Taylor's Power Law, and the dashed line (---) represents the Poisson distribution.

aggregation has been shown to decrease between successive developmental stages of cabbageworm larvae (Pieris rapae) and the alfalfa weevil (Hypera postica) (Harcourt, 1961b; Miller et al., 1972). Harcourt (1961b) attributes the increase in randomness to density-dependent biological processes.

5.3.2 Determination of Sample Size

For sample size selection, S^2 from equation [5.1] was replaced by the expression (antilog) in equations [5.4], [5.5] and [5.6] to yield:

for eggs: $$n_o = \left(\frac{t_{\alpha/2}}{C}\right)^2 * \frac{23.55}{\bar{X}^{.74}} \qquad [5.7]$$

for P1 larvae: $$n_o = \left(\frac{t_{\alpha/2}}{C}\right)^2 * \frac{2.07}{\bar{X}^{.88}} \qquad [5.8]$$

for P2 larvae: $$n_o = \left(\frac{t_{\alpha/2}}{C}\right)^2 * \frac{1.64}{\bar{X}^{.91}} \qquad [5.9]$$

Sample sizes were determined for three levels of margin of error (.10, .15, and .20) at 70% and 95% confidence intervals (Figs. 17, 18, and 19). As expected for aggregated distributions, the number of sample units required is inversely proportional to the population density. For the range of population densities observed in this study (0 - 3 and 0 - 5 individuals per sample unit for eggs and larvae, respectively), precise estimates are difficult to obtain for 95% confidence intervals unless very large numbers of samples are collected. For survey purposes, I

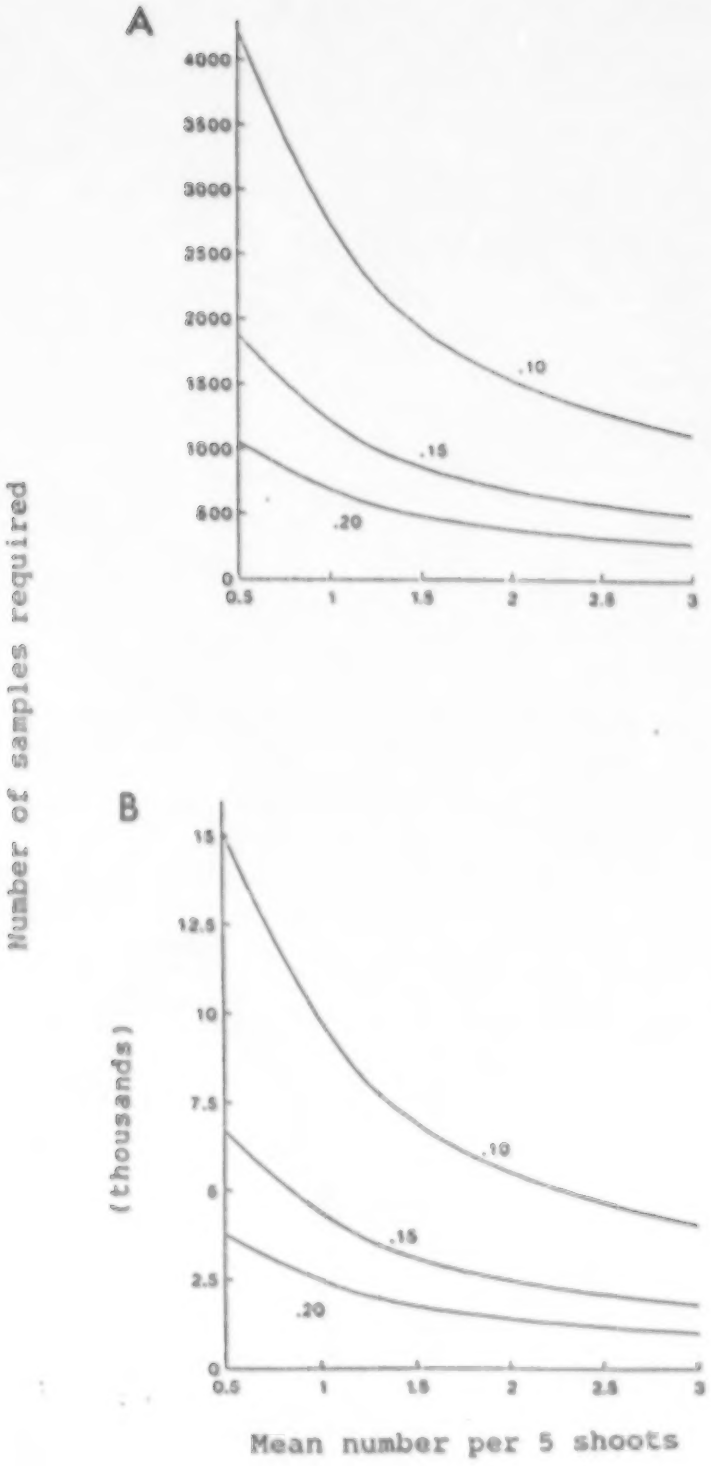
recommend the 70% confidence interval. The number of samples required were greater than the suggested number for alfalfa weevil larvae (Guppy et al., 1975). This could be due to differences in spatial distribution of the two species.

The cost (in person-minutes) per five-shoot bouquet to collect (C_c) one bouquet was .5 minutes and to process (C_p) one bouquet was 14.5 minutes for eggs and 11.5 minutes for larvae (P1 and P2). The total time (C) required to process a specified number of samples is as follows:

$$C = n_s (C_c + C_p) \qquad [5.10]$$

Table 8 gives cost estimates for sampling at the 70% confidence interval and three levels of precision. The cost of sampling for P1 and P2 larvae was far lower than that for eggs.

Fig. 17 (a, b). Sample sizes (eggs) required to achieve given precision levels at different mean densities per five shoot bouquet (based on eq. [5.7]). (a) 70% confidence interval and (b) 95% confidence interval.


A
4000
3500
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1500
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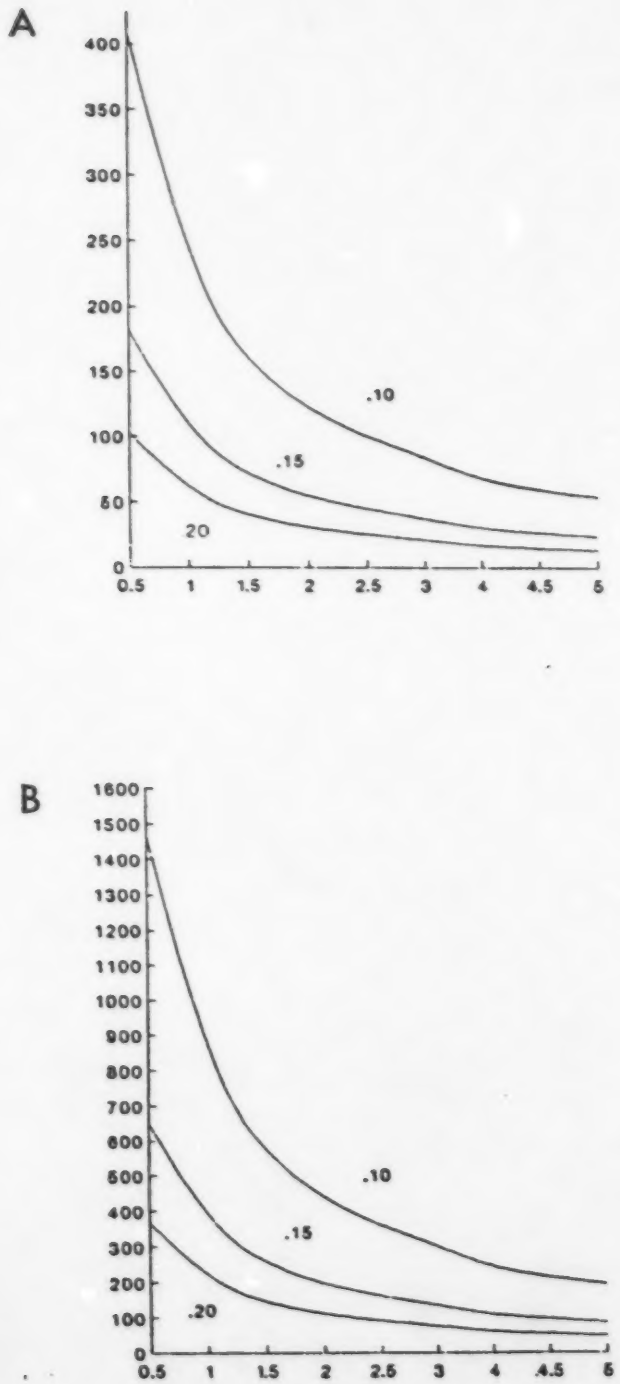
500
0
.10
.15
.20
0.5
1
1.5
2
2.5
3
B
15
12.5
10
7.5
5
2.5
0
.10
.15
.20
0.5
1
1.5
2
2.5
3
Number of samples required
(thousands)
Mean number per 5 shoots

Fig. 18 (a, b). Sample sizes (P1 larvae) required to achieve given precision levels at different mean densities per five shoot bouquet (based on eq. [5.8]). (a) 70% confidence interval and (b) 95% confidence interval.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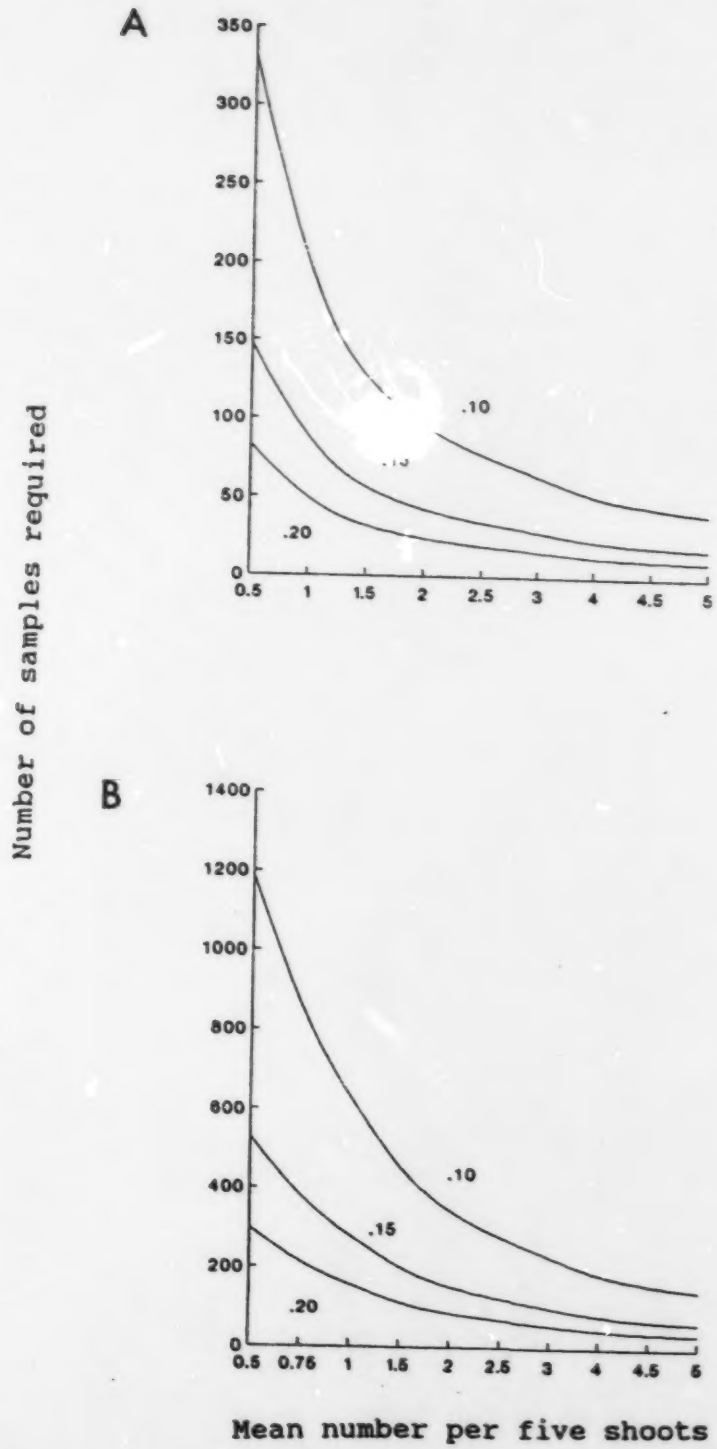
Number of samples required
Mean number per 5 shoots

Fig. 19 (a, b). Sample sizes (P2 larvae) required to achieve given precision levels at different mean densities per five shoot bouquet (based on eq. [5.9]). (a) 70% confidence interval and (b) 95% confidence interval.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Number of samples required
Mean number per five shoots

Table 8. Cost (person-minutes) for sampling LCLW eggs and larvae (P1 and P2) at the 70% confidence interval and three levels of precision (.10, .15, and .20) for specific population densities (based on eq. [5.10]).

Mean number per bouquet	Eggs			P1			P2		
	.10	.15	.20	.10	.15	.20	.10	.15	.20
0.5	63300	28100	1055	4910	2180	1225	4000	1770	995
1.0	37900	16850	630	2665	1185	665	2110	940	530
2.0	22700	10100	380	1450	640	360	1125	500	280
3.0	16834	7480	280	1010	450	250	775	345	195
4.0	-	-	-	785	350	195	595	265	150
5.0	-	-	-	645	285	160	485	215	120

6 INSECTICIDAL CONTROL OF LCLW LARVAE AND ADULTS

6.1 Introduction

Though insecticide trials were conducted against LCLW in the 1950's (Beckham, 1956), the results obtained are no longer appropriate, except perhaps in respect to the timing of application and target stage.

In 1986, the only insecticide registered for control of LCLW was Guthion. However, insecticides registered for control of the alfalfa weevil, Hypera postica, were chosen for efficacy tests of LCLW. The objectives of this study were to determine optimal timing of insecticide application to control LCLW larvae and adults and to determine efficacies of different insecticides.

6.2 Materials and Methods

Tests for efficacy of insecticidal control were carried out on three fields in 1986. On June 18, Guthion (420 g Ai/ha) and Furadan (280 g Ai/ha) were applied to a first year field (field H) and a second year field (field R) (both were pre-bloom). On July 8, the following insecticides were applied to a first year red clover field (peak-bloom): Furadan (140 and 280 g Ai/ha), Guthion (210 g Ai/ha), Lorsban (420 g Ai/ha), Decis (12.5 g Ai/ha), Pounce (140 g Ai/ha), Sumithion (420 g Ai/ha), and Baythroid (20 and 30 g Ai/ha). For each insecticide, applications were replicated twice in a randomized complete block design. Larval and pupal

estimated
populations were by collection of 20 shoots per plot. Adult populations were assessed by making 25 sweeps with a 38cm sweep net per plot. Larvae, pupae and adults were sampled 1 day prior to, and 2, 7 and 15 days after treatment.

6.3 Results and Discussion

On June 18 (1986), Guthion and Furadan were applied to control larval LCW (Table 9). Two fields were used, both with red clover in the pre-bloom stage. Insecticide treatments resulted in control ranging from 44 to 67.6% 2 days post-treatment. At 6 days post-treatment, control was lower in field R than in field H. This is likely due to the fact that larval populations were beginning to decline as development to pupae occurred in field R.

On July 8, seven insecticides were applied to control P2 larvae and adults (primarily late summer adults) (Table 10). The red clover was in peak bloom. Baythroid (20 g Ai/ha) provided the most effective control of larvae at 2 days post-treatment. At 7 days post-treatment, Baythroid (both rates) and Furadan (both rates) provided effective control of larvae. Pounce and Sumithion provided maximum control of adults at 2 days post-treatment. After 7 days, Furadan (280 g Ai/ha) and Baythroid (both rates) provided the most effective control of adults.

Table 9. Percentage control of LCLW larvae in 1986 by Furadan and Guthion.

Field	Insecticide	Application Rate (g Ai/ha)	Days Post-Treatment 2	6
R	Furadan	280 (280)	67.6	30.8
R	Guthion	420	59.5	30.8
H	Furadan	280	44.0	50.0
H	Guthion	420	64.0	94.4

$$\% \text{ Control} = \frac{\text{Number in untreated plots - Number in treated plots}}{\text{Number in untreated plots}} \times 100$$

Table 10. Percentage control of LCLW larvae and adults in 1986 by various insecticides.

Insecticide	Application Rate (g Ai/ha)	Days Post-Treatment 2		7	
		Larvae	Adults	Larvae	Adults
Furadan	280	18.1	62.5	79.1	70.2
Furadan	140	-9.0	37.5	83.3	44.7
Guthion	210	36.3	37.5	54.1	53.2
Lorsban	420	54.5	50.0	45.8	55.3
Decis	12.5	-45.0	87.5	75.0	-25.5
Pounce	140	45.4	-50.0	70.8	-34.0
Sumithion	420	27.2	-37.5	45.8	48.9
Baythroid	20	81.8	75.0	79.1	59.8
Baythroid	30	27.2	75.0	83.3	68.1

$$\% \text{ Control} = \frac{\text{Number in untreated plots - Number in treated plots}}{\text{Number in untreated plots}} \times 100$$

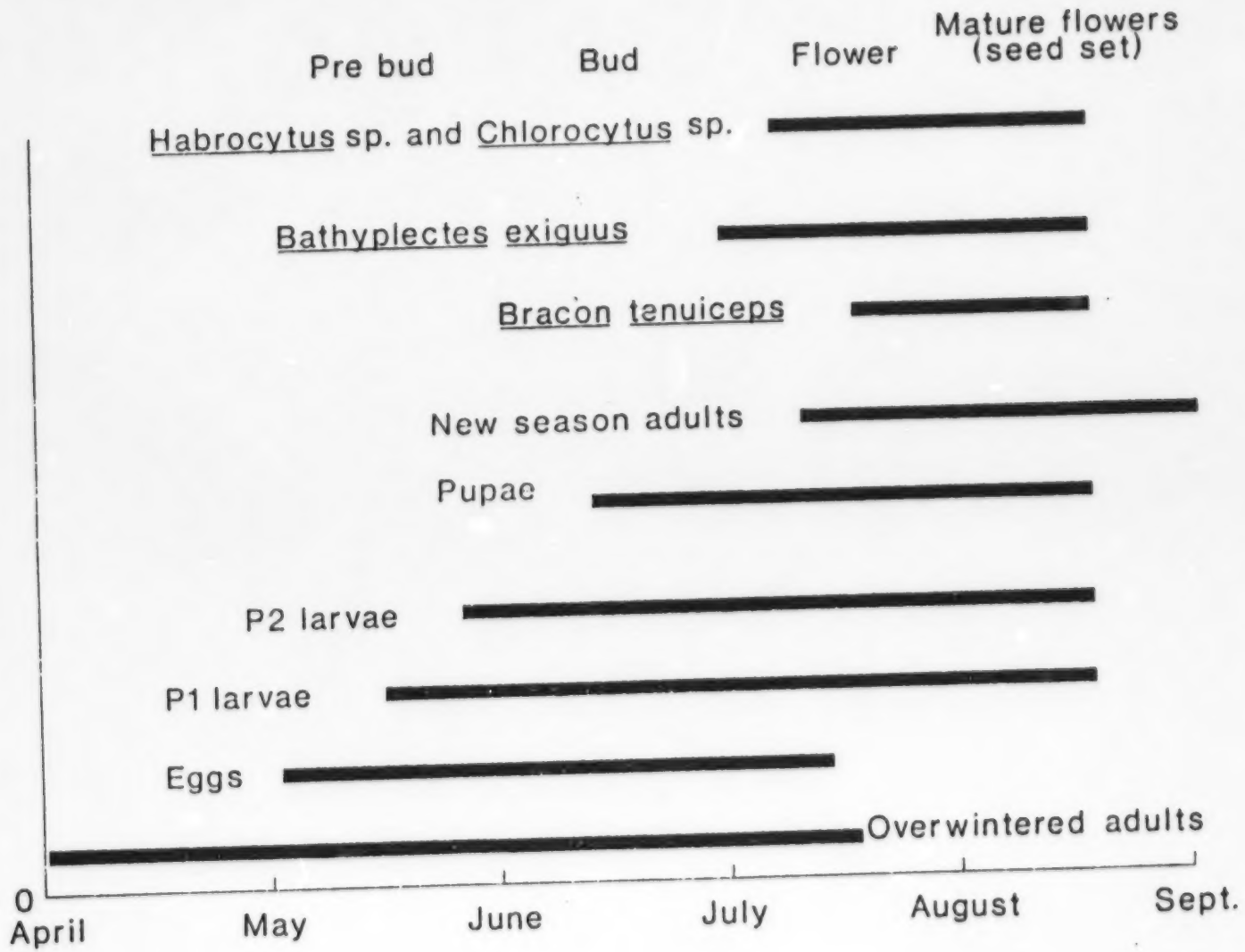
7 SUMMARY AND CONCLUSIONS

7.1 Summary

During 1986 and 1987, a study of the lesser clover leaf weevil (LCLW), Hypera nigrirostris (Coleoptera: Curculionidae), was carried out with four objectives in mind. First, to determine seasonal occurrence, duration and abundance of each LCLW developmental stage. Second, to identify parasitoids associated with LCLW and determine their effect on LCLW populations. Third, to describe and quantify weevil damage to vegetative and reproductive structures of red clover (Trifolium pratense) and determine relationships between larval densities and damage to stipules, buds and flowerheads. Fourth, to determine the spatial distribution of eggs and larvae and to develop an optimal sample plan for estimating density of egg and larval populations of LCLW.

Eggs were laid subepidermally in stipules, stems and leaves. Often, eggs were found individually, though clusters of two, three and four did occur. In 1987, eggs were collected from May 3 to July 13 (Fig. 20); largest numbers occurred on May 25. LCLW larvae developed through four larval instars. First and second instar larvae were grouped into P1 larvae and third and fourth instar larvae were grouped into P2 larvae. P1 and P2 larvae were separated by characteristics of the headcapsule, cervical shield, and body (color and length). After hatching, P1 larvae moved to suitable feeding sites including stipules, buds and folded

Fig. 20. Seasonal phenologies of red clover, LCLW eggs, larvae (P1 and P2), pupae, and adults, B. tenuiceps, B. exiguus, Chlorocytus sp., Habrocytus sp.


Pre bud
Bud
Flower
Mature flowers (seed set)
Habrocytus sp. and Chlorocytus sp.
Bathyplectes exiguus
Bracon tenuiceps
New season adults
Pupae
P2 larvae
P1 larvae
Eggs
Overwintered adults
0
April
May
June
July
August
Sept.

leaves. P2 larvae fed in stipules, buds, and flowerheads. They remained in these sites while they fed on young plant tissue. P1 larvae were collected in the field from mid May until mid August (Fig. 20). P2 larvae were collected from late May and early June until mid August (Fig. 20). Pupae constructed lacy cocoons on flowers, leaves, stipules and ground debris. Pupae were collected from late June until mid August (Fig. 20). Adult LCLW were brown after emergence from cocoons and approximately 1 week later they were bright green. Overwintered adults were blue-green. Adults overwintered in red clover fields under debris. In April and May, adults began feeding and mating; oviposition occurred soon after.

Hymenopterous parasitoids were reared only from LCLW larvae and pupae and included one braconidae (Bracon tenuiceps), three Ichneumonidae (Bathyplectes exiguus, Scambus (Scambus) decorus (Walley), and Gelis sp.), and four Pteromalidae (Dibrachoides dynastes, Chlorocytus sp. and two species of Habrocytus sp.). B. tenuiceps and B. exiguus were the two most abundant parasites. Parasites were collected during late June, July and August (Fig. 20). Habrocytus sp. and Chlorocytus sp. were hyperparasites of B. exiguus.

In spring, feeding by adults resulted in minimal damage to red clover stipules, leaves and stems. P1 larvae caused minor damage to stipules, leaves and buds. P2 fed on stems, stipules, buds and flowerheads, and caused the greatest amount of damage to red clover. Linear relationships between the number of P2 larvae and the number of damaged stipules, buds and flowerheads were

determined.

The spatial distribution of eggs, P1, and P2 larvae was shown to be aggregated. An optimal sample plan, based on the spatial distribution of each stage, was developed for eggs, P1 and P2 larvae.

In 1986 seven insecticides were tested for control of LCLW larvae and adults. Furadan (280 g Ai/ha) and Guthion (420 g Ai/ha) gave better than 50% control 2 days post-treatment. A second test showed Baythroid (20 and 30 g Ai/ha) and Furadan (280 g Ai/ha) to give better control of larvae and adults than other insecticides tested.

7.2 Conclusions

Red clover is valuable to growers in terms of seed production, increased soil fertility, and improved soil structure. Weevil phenology appeared to be coordinated with red clover such that the most destructive developmental stages (i.e. P2 larvae) occurred when red clover stipules, buds and flowers were present. This made red clover susceptible to damage caused by LCLW. Although low LCLW populations and minor damage to red clover occurred in 1986 and 1987, LCLW may cause severe reductions in red clover seed yield; in 1985 seed yield losses of 30-90% in an area of c. 12,000 ha were experienced as a result of heavy LCLW infestations (Craig, 1985). Linear regression models showed that P2 larval densities greater than three per shoot could damage up to 50% of buds and flowerheads. It appears that the parasitoid complex, in combination with abiotic factors, may

be capable of maintaining weevil populations at low densities in most years. LCLW (eggs, P1 and P2 larvae) populations should be monitored by collection of 5 shoot bouquet samples in June and early July, to assess LCLW larval populations.

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